PB-245 065

AIR POLLUTION CONTROL TECHNOLOGY AND COSTS: SEVEN SELECTED EMISSION SOURCES

Industrial Gas Cleaning Institute

Prepared for:

Environmental Protection Agency

December 1974

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268264

PB 245 065

EPA-450/3-74-060
DECEMBER 1974

AIR POLLUTION CONTROL TECHNOLOGY AND COSTS: SEVEN SELECTED EMISSION SOURCES

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-74-060	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Air Pollution Control Technology and Costs Seven Selected Emission Sources		5. REPORT DATE December, 1974 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO. 47.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Industrial Gas Cleaning Institute P.O. Box 1333 Stamford, Connecticut 06904		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-1091
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency Office of Air and Waste Management Office of Air Quality Planning and Standards Research Triangle Park, No. Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Under this contract, the Industrial Gas Cleaning Institute collected and formalized data on air pollution abatement for seven selected industrial emission sources. These seven sources were:

Kraft Paper Mills, Ferroalloy Furnaces, Grain Cleaning Houses, Glass Melting Furnaces, Crushed Stone and Aggregate, Asphalt Saturation, and Surface Coating Operation.

For each source area studied, costs of conventionally applied pollution control systems are presented for a range of plant sizes and control efficiencies.

PRICES SUBJECT TO CHANGE

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	XXXXXXXXXXXXXX
Air Pollution Performance Air Pollution Control Equipment Cost Estimates Cost Engineering Mechanical Collectors Electrostatic Precipitators Incinerators Scrubbers Fabric Filters	Air Pollution Control Kraft Processes Ferroalloy Crushed Stone & Aggregate Glass Furnaces Grain Cleaning Surface Coating	- Asphalt Saturation

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 334
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $9.50

EPA Form 2220-1 (9-73)

EPA-450/3-74-060

AIR POLLUTION CONTROL TECHNOLOGY AND COSTS: SEVEN SELECTED EMISSION SOURCES

KRAFT MILL RECOVERY BOILERS, FERROALLOY FURNACES, FEED AND GRAIN PROCESSING, GLASS MELTING FURNACES, CRUSHED STONE AND AGGREGATE INDUSTRY, ASPHALT SATURATORS, INDUSTRIAL SURFACE COATINGS

by

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Contract No. 68-02-1091

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Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

December 1974

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Publication No. EPA-450/3-74-060

Contract Number 68-02-1091

Air Pollution Control Technology And Costs In Seven Selected Areas

Including
Kraft Mill Recovery Boilers
Ferroalloy Furnaces
Feed and Grain Processing
Glass Melting Furnaces
Crushed Stone and Aggregate Industry
Asphalt Saturators
Industrial Surface Coatings

Final Report

(Completed 15 May, 1975)

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STATEMENT OF PURPOSES

The Industrial Gas Cleaning Institute, incorporated in 1960 in the State of New York, was founded to further the interests of manufacturers of air pollution control equipment, by

encouraging the general improvement of engineering and technical standards in the manufacture, installation, operation, and performance of equipment

disseminating information on air pollution; the effect of industrial gas cleaning on public health; and general economic, social, scientific, technical, and governmental matters affecting the industry, together with the views of the members thereon; and

promoting the industry through desirable advertising and publicity.

ACKNOWLEDGEMENT

The efforts of the IGCI Engineering Standards Committee in the preparation, editing and reviewing of this Report are gratefully acknowledged:

Harry Krockta, Chairman, The Ducon Company, Inc.
G. L. Brewer, Air Correction Division, UOP
C. A. Gallaer, Envirotech Corp.
N. D. Phillips, Fuller Co., Dracco Products
E. J. Malarkey, Wheelabrator-Frye, Inc., Air Pollution Control Division

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I. INTRODUCTION

The Industrial Gas Cleaning Institute (IGCI) is an association of manufacturers of gas cleaning equipment, used primarily for the abatement of air pollution. Under this contract, the IGCI is collecting and formalizing data on air pollution control in seven industrial areas selected by the EPA. These areas are:

1. Kraft Mill Recovery Boilers	Phase I
2. Ferroalloy Furnaces	
3. Feed and Grain Cleaning Houses	
4. Glass-Melting Furnaces	
5. Crushed Stone and Aggregate Plants	Phase II
6. Asphalt Saturation Plants	
7. Industrial Surface Coating Operations	

This final report contains all of the technical information assembled for both the three process areas of Phase I and the four process areas of Phase II. The technical material consists of a narrative description of each of the process areas tabulated above, specifications for air pollution abatement equipment for each, and a summary of capital and operating costs for equipment obtained from the IGCI member companies in response to the specifications. The following section summarizes all of the technical data assembled.

II. TECHNICAL DATA

This section contains all of the data collected as a part of this program. This includes information on process descriptions, air pollution control requirements, specifications, and capital and operating costs for abatement equipment used in these industries. Narrative material was generated by the combined efforts of Air Resources, Inc. personnel acting as editors and coordinators for the program, and the most qualified personnel of the IGCI member companies active in each field. The cost data, however, is entirely the product of companies judged most qualified. In addition to IGCI member companies, some non-members participated by supplying cost information. These companies prepared cost estimates independently of one another. Air Resources, Inc. consolidated the data and edited it with regard to format only.

A. GENERAL DESCRIPTION

1. Format

This study includes seven industrial areas, divided into two groups, each of which were covered by a separate earlier phase report. In this final report, the two phases are combined and summarized.

There are seven sections in this report, each covering one of the industrial areas. For each area, the following format is used:

1. Description of the Process
   - a. Manufacturing or Production Aspects
   - b. Air Pollution Control Equipment
2. Specifications and Costs
   - a. Electrostatic Precipitators
     - (1) Specifications
     - (2) Capital Costs
     - (3) Operating Costs
   - b. Wet Scrubbers
   - c. Fabric Filters
   - d. Others
3. Summary Comments

This material will not be presented in outline form, nor will each item necessarily be included for each process area.

2. Selection of Applicable Equipment Types

Emissions from the industries studied under this contract fall into two broad classes: particulate matter, and hydrocarbons. Five of the seven study areas, including all of those in Phase I, are concerned primarily with emissions of particulate matter. These five include:

Kraft Mill Recovery Boilers (Conventional and Controlled Odor Types)
Ferroalloy Furnaces
Feed and Grain Cleaning Houses
Glass Melting Furnaces
Crushed Stone and Aggregate Plants

Odor problems in kraft mills are normally dealt with through process modification. One common modification for odor control is the "controlled odor" type of recovery boiler. While the kraft mill recovery boiler study investigates control of particulate emissions from both kinds of boilers, the study does not cover odor abatement techniques or performances, per se. It includes the controlled odor type boiler only because it represents a common boiler type, currently in use, requiring particulate emission control.

The other two study areas are concerned primarily with hydrocarbon emissions:

Asphalt Saturation Plants
Industrial Surface Coating Operations

All of the conventional pollution abatement devices will be included in this seven industry study, as indicated below:

Control of Particulate Matter	Control of Hydrocarbons
Electrostatic Precipitators	Incinerators
Fabric Filters	Adsorption Units
Wet Scrubbers	Absorption Units

In general, a given process is amenable to control by more than one type of device. The Engineering Standards Committee of the IGCI has been responsible for selecting the types which will be considered in this program. In many areas, the EPA is conducting simultaneous programs in which industrial surveys, source testing, and other programs may furnish additional insight into the equipment types predominating in well-controlled installations. This information was incorporated into the judgments reached by the Engineering Standards Committee through a series of technical exchange meetings with the EPA.

Selections of equipment types to be studied were made during several Engineering Standards Committee meetings and technical exchange meetings. Present at all of the technical exchange meetings were representatives of the following groups:

EPA	Economics Analysis Branch
EPA	Industry Studies Branch
IGCI	Technical Director
IGCI	Engineering Standards Committee
ARI	Project Coordinator

The end results of this selection process are presented in Table 1.

3. Basis for Preparing Specifications and Bid Prices

The degree of reduction of emissions required in a given application will influence the cost significantly for wet scrubbers and electrostatic precipitators. The costs of fabric filters, mechanical collectors, and incinerators are, on the other hand, relatively insensitive to the efficiency level specified. In all cases, the cost is directly related to size or gas handling capacity required.

TABLE 1

ABATEMENT EQUIPMENT TYPES SELECTED FOR THE SEVEN PROCESS AREAS

Process Area	Emission Source	Equipment Type
Kraft Mill Recovery Boilers	Conventional Boiler	Electrostatic Precipitator
	Controlled Odor Boiler	Electrostatic Precipitator
Ferroalloy Furnaces	Open Furnace	Fabric Filter
Feed and Grain Processing	Cleaning House	Fabric Filter
Glass-Melting Furnace	Soda-Lime Glass-Melting Furnace	Electrostatic Precipitator Wet Scrubber Fabric Filter
Crushed Stone and Aggregate Plant	Secondary and Tertiary Rock Crushers	Wet Scrubber Fabric Filter
	Conveyor Transfer Points	Wet Scrubber Fabric Filter
Asphalt Saturation Plant	Asphalt Saturator	Wet Scrubber (absorber) Thermal Incinerator High Energy Air Filter
	Asphalt Blow Still	Thermal Incinerator
Industrial Surface Coating Operations	Spray Coating Chambers	Carbon Adsorption Thermal Incinerator Catalytic Incinerator

In order to make a meaningful comparison of capital and operating costs, it is necessary to specify the performance level, or degree of reduction of emissions required. Two levels of performance were specified for most types of equipment so that costs could be related to the degree of emission reduction as well as to gas handling capacity. The two performance levels are called "medium efficiency" and "high efficiency." For each of the seven process areas, numerical collection efficiencies were specified for each performance level during the technical exchange meetings with EPA. In those cases where fabric filters were applied, only one performance level was specified, the "high efficiency" level.

The efficiencies were chosen on the basis of the following criteria:

High Efficiency	— A sufficiently low grain loading to expect a clear stack.
Medium Efficiency	— The process weight table published in the Federal Register April 7, 1971, or other process operating emission factors related to the specific industry under study.

The process weight table used is presented in Table 2. Table 3 lists the collection efficiencies specified for each case.

Several simplifications were made in the preparation of the specifications which have some bearing on the results which are reported here. These should be kept in mind when using the prices, operating costs, etc. The form of the specification for equipment may have an influence over the price quoted. Overly-restrictive specifications may add 5% to 10% to the equipment price, without a corresponding increase in value received by the purchaser. In each of the cases presented in this report, prices are based on a specification which covers most of the conditions of purchase in an equitable way. Instead of writing each specification independently, the participants agreed upon the general terms and conditions to be specified, and these conditions were made identical for each specification. The final specification in each case was made by inserting one section of descriptive material and one section of operating conditions pertaining to the specific application into the standard format. To avoid unnecessary repetition, a sample of the complete specification for one of the applications is included as Appendix A to this report. Only the pages pertinent to specific applications are contained in the body of the report.

Prices were requested in such a way as to indicate three bases:

TABLE 2

PROCESS WEIGHT TABLE FOR MEDIUM EFFICIENCY FOR PARTICULATE MATTER COLLECTION CASES ONLY*

Process Weight Rate (lb/hr)	Rate of Emission (lb/hr)
100	0.551
200	0.877
400	1.40
600	1.85
800	2.22
1,000	2.58
1,500	3.38
2,000	4.10
2.500	4.76
3,000	5.38
3,500	5.96
4,000	6.52
5,000	7.58
6,000	8.56
7,000	9.49
8,000	10.44
9,000	11.2
12,000	13.6
16,000	16.5
18,000	17.9
20,000	19.2
30,000	25.2
40,000	30.5
50,000	35.4
60,000 or more	40.0

*Federal Register April 7, 1971

TABLE 3

COLLECTION EFFICIENCIES SELECTED FOR SEVEN PROCESS AREAS

Emission Source	Emission Type	Equipment Type	Medium Efficiency	High Efficiency
Kraft Mill Recovery Boilers	Particulate Matter	Electrostatic Precipitator	1.7 lb/ADT (3) (0.035 gr/DSCF)	0.02 gr/DSCF (1.0 lb/ADT)
Ferroalloy Furnaces	Particulate Matter	Fabric Filter	(1)	0.01 gr/ACF
Feed & Grain Processing	Particulate Matter	Fabric Filter	(1)	0.01 gr/ACF
Glass-Melting Furnace	Particulate Matter	Electrostatic Precipitator	(1)	0.01 gr/ACF
		Wet Scrubber	(1)	0.01 gr/ACF
		Fabric Filter	(1)	0.01 gr/ACF
Crushed Stone and Aggregate Industry				
Secondary and Tertiary Rock Crushers	Particulate Matter	Wet Scrubber	(2)	0.01 gr/ACF
		Fabric Filter	(1)	0.01 gr/ACF
Conveyor Transfer Points	Particulate Matter	Wet Scrubber	0.04 gr/ACF	0.01 gr/ACF
		Fabric Filter	(1)	0.01 gr/ACF
Asphalt Saturator	Hydrocarbons	Wet Scrubber (absorber)	(1)	8 lb/hr
		Thermal Incinerator	98%	99%
		High Energy Air Filter	(1)	98%
Asphalt Blow Still	Hydrocarbons	Thermal Incinerator	(1)	99%

(1) Only one efficiency specified
(2) Process Weight Table
(3) ADT = Air dried ton of pulp

1. Air pollution control device. This includes only the flange-to-flange precipitator, fabric filter, scrubber, etc.
2. Air pollution control auxiliary equipment. This includes major items such as fans, pumps, etc.
3. Complete turnkey installation. This includes the design, all labor and materials, equipment fabrication, erection, and startup.

In order to maintain a consistent approach to quoting in each area, the specifications were written around the air pollution control device. The process description was, however, made general enough to allow the bidders to quote on the auxiliary equipment, such as fans, pumps, solids handling devices, etc., and to quote on an approximate installation cost. A complete set of instructions for quoting is given in Appendix B.

Labor costs vary from one location to another, and it was not possible to establish the complex pattern of variations in turnkey prices which occur as a function of local variations in hourly rates, productivity, and availability of construction tradesmen. In order to provide a consistent basis for the preparation of price quotations, the cost indices given in Appendix C were used. These figures do not take productivity differences into account and may understate the variations in cost from one city to another.

The participating companies were instructed to estimate the installation costs as though erection or installation of the system would be in Milwaukee, Wisconsin or another city relatively convenient to the participant's point of shipment with a labor index near 100. Readers are cautioned to take local labor rates and productivity into account when making first estimates of air pollution control system installed costs based on the data in this report. Appendix D shows the tabulated hourly rates for various construction trades (based on national averages) which may be useful for this purpose.

Considerable emphasis was placed on the estimation of operating costs. Manufacturers submitting costs for equipment were asked to estimate the operating costs in terms of utility requirements, maintenance and repair labor, and operating labor. These were requested in terms of quantity required, rather than cost. This was done because the operating costs will be analyzed in terms of standard utility and labor rates.

Air pollution control costs for the Industrial Surface Coatings section of this report were not obtained in the same fashion as costs for the other three study areas. Equipment specifications were not prepared nor were specific bids solicited. Instead, the three firms selected as "most expert reviewers" reviewed generalized economics for the common types of abatement systems used for control in this industry. These generalized economics are presented as part of the narrative portion of the report.

4. Presentation of Data

Estimates of both capital cost and annual operating cost are presented for each type of abatement equipment applied to each of the seven industries covered under the program. In general, the capital cost data are presented in one table, which shows the averaged details of the bids submitted for each application, followed by a graph. The graph shows the capital cost for the abatement device, the total equipment cost, and the turnkey system cost correlated with plant size.

Operating costs are also presented in similar fashion. A table shows averaged annual estimates of labor, maintenance, and utilities, and an estimate of the annualized capital charge, computed as a percentage of total system capital cost. Graphs present direct annual cost and total annual cost correlated with plant size.

B. PROCESS DESCRIPTION AND COSTS

1. KRAFT PULP MILLS

Paper has evolved from early man's use of bark, ivory, papyrus, and parchment in an effort to record activities and events. In the early nineteenth century, paper production methods employed rags as the primary raw material. Improving levels of communication created a rapidly increasing demand for paper leading to increased production and a subsequent scarcity of rags. Inventors, however, responded to this scarcity by developing production methods which utilized wood. The second half of the nineteenth century saw development of first mechanical, and then chemical methods for pulping wood.

Since the turn of the century, wood has become the most important source of fiber for paper pulps. Sulfate, or kraft, pulping is one of two main chemical processes used to convert wood to papermaking fibers. Sulfite pulping, similar in many process details to the kraft method, also employs chemical means but produces pulp with lower physical strength and opacity. Other processes in use are mechanical pulping, where logs are reduced to fiber by physical grinding, and "chemi-mechanical" pulping which combines both chemical and mechanical methods of defibration. The soda process, which is similar in many respects to the sulfite and sulfate process accounts for only a small percentage of the pulp produced.

The kraft process, introduced to the United States in 1908, is aptly named because kraft is the German word for strong and the kraft product is characterized by superior physical strength. In 1966, more than 63% of the totai U.S. production of pulp was made by the kraft process. The majority of new chemical pulp manufacturing facilities built since then, or currently in the design stage, also use the kraft process.

KRAFT PROCESS DESCRIPTION

In kraft or sulfate pulping, separation of fibers is accomplished by chemical treatment to dissolve the lignin which bonds wood fibers together. The chemical reactions responsible for this defibration involve hydrolysis of lignins in the wood to alcohols and acids. This hydrolysis also produces mercaptans and sulfides which are responsible for the familiar odor around sulfate-pulp mills. This reaction takes place in the digesters. The chemicals used in kraft milling are too expensive to discard. Consequently, much of the pulping process is devoted to recovery and reuse of these chemicals.

It is possible to produce relatively pure cellulose fiber by the kraft process, since almost fifty percent of the log is extracted. Papers from this pulp have high

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physical strength, bulk, and opacity; low unbleached brightness; and relatively poor sheet formation properties. Both bleached and unbleached sulfate pulps are used as packaging papers, container board, and a variety of printing and bond papers. The kraft process consists of the following steps.

1. Logs are debarked. The bark is often used as a fuel in the bark power boiler along with either coal, gas, or oil. Bark power boilers, as an emission source, have been studied in depth under a separate EPA contract, No. 68-02-0301, entitled "Air Pollution Control Technology and Costs in Nine Selected Areas". In some areas the bark is prepared for a garden mulch. However, with the increasing cost of other fuels, it must be considered as a potential source of energy.

2. The debarked logs are conveyed to chippers which are large rotating discs holding four or more long heavy knives. The chipper reduces the wood to small chips. The chips are screened for size to separate those of the desired size from those that are too large and from sawdust. Oversize chips are sent through crushers to reduce them to the proper size. Proper sized chips are send to a chip bin or silo where they may be joined by chips that have arrived by rail or truck from lumber veneer, and ply-wood mills.

3. From the chip bin the wood chips are fed to the digester. Two types of digesters in wide use today are the continuous digester and batch digester. There are also a few rotary digesters still in use. Continuous digesters are tall towers that are fed chips and cooking liquor at the top, while pulp, along with spent cooking liquor, are continuously withdrawn to the blow tank. Batch digesters consist of a series of vertical vessels. The individual vessels are charged with chips, and cooking liquor is added. The vessel is closed up and pressurized with live steam. The cooking time will vary from 2 to 5 hours at a temperature of about 350°F and a pressure of 100 to 125 psig. The cooking liquor is composed primarily of a 12.5% solution of sodium sulfide and caustic soda. It is often referred to as white liquor because of its color.

4. When the operator determines that the cook is finished, he will reduce the pressure to 80 psig by opening the blow valve on the bottom of the vessel and allowing the pulp, along with the spent liquor, to be blown to the blow tank. Blow tanks are vented to an accumulator.

5. The pulp is separated from the cooking liquor by filtration and washing.

6. The spent liquor (black liquor), now containing about 15% solids, is transferred to the weak black liquor storage tank prior to the recovery of

its chemical constituents for reuse in the digester.

7. The washed pulp passes to the screen room where slivers of uncooked wood, and knots which failed to disintegrate, are separated from the pulp. Knots removed in this step are sent to waste, but screenings are refined and returned to the process.

8. If the pulp is to be bleached (by an agent which oxidizes and destroys dyes which were formed from tannins present in the wood and intensified by sulfides in the cooking liquor), it is done at this time.

9. After the pulp is bleached or prepared as desired and thickened, it is sent to storage.

10. If the end product is pulp, "lapping" is performed on an endless felt belt which carries pulp sheets through a series of squeeze and hot press rolls. The resulting "laps", which contain approximately 40% air-dry fiber, are subject to pressures up to 3000 psig. This pressure, exerted by hydraulic presses, raises the air-dry fiber content to between 50 to 60%. If the pulp is to be made directly into paper, the pulp from storage will go through refining before it goes to the wet end of the paper machine.

The recovery and reuse of chemicals from the weak black liquor makes kraft pulping economically feasible. The recovery system, in general, and the recovery furnace, in particular, are the primary subjects of this narrative.

The weak black liquor removed from the pulp in the washer (Step 5) contains about 96% of the alkali originally charged to the digester. Alkali is present as sodium sulfate, salt, silica, and trace quantities of other inorganic compounds.

The recovery system portion of the process is shown schematically on Figure 1. It consists of the following steps.

11. The weak black liquor is pumped from storage to the multiple-effect evaporators. These evaporators use steam to concentrate the liquor to about 50% solids. There is no direct contact between the steam and black liquor in these evaporators.

12. At this point, the liquor is concentrated to a solids content of at least 63%; necessary for it to ignite and sustain combustion when sprayed into the recovery furnace. This concentrated black liquor is termed "strong black liquor". Several alternative schemes are used for the concentration step. These are discussed in detail in the section entitled "Nature of the Gaseous Discharge".

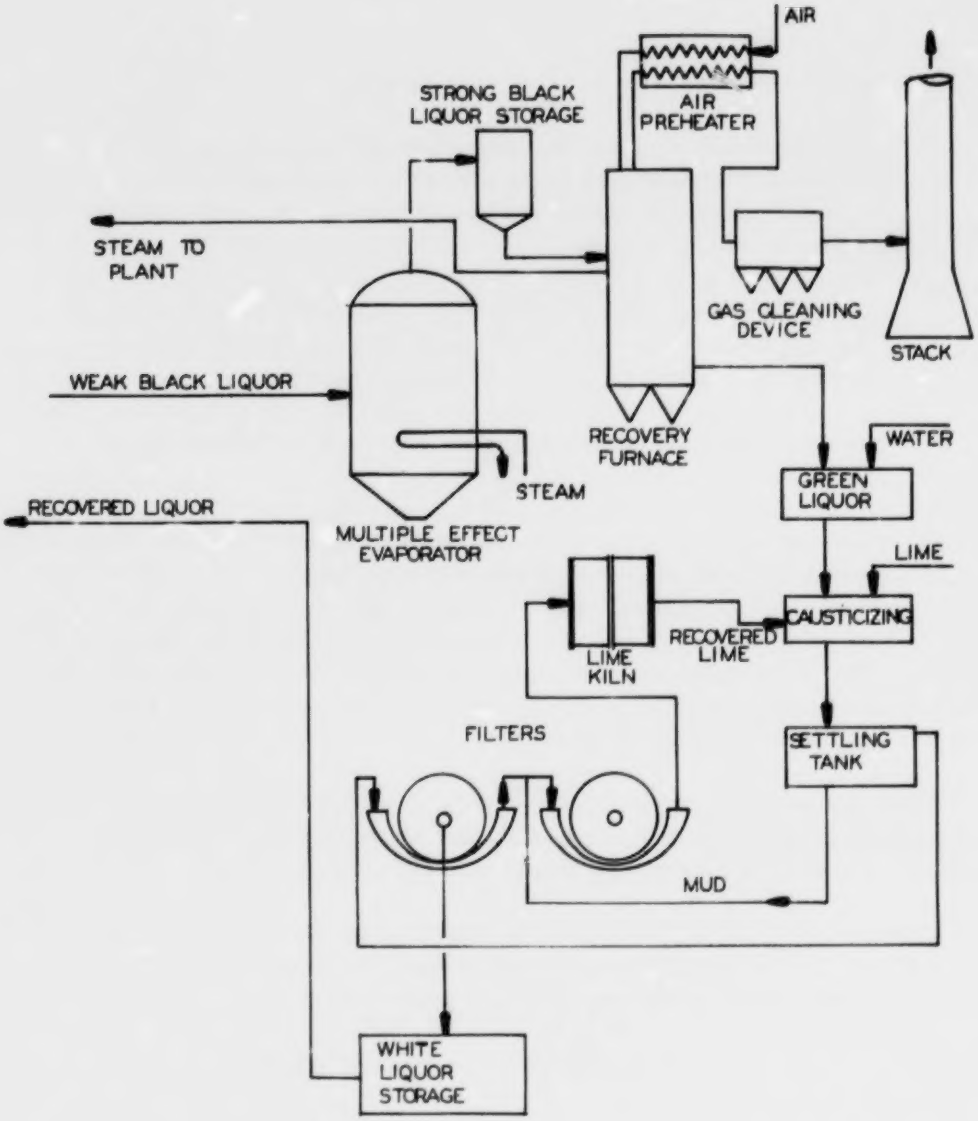

AIR
STRONG BLACK LIQUOR STORAGE
AIR PREHEATER
STEAM TO PLANT
GAS CLEANING DEVICE
STACK
WEAK BLACK LIQUOR
RECOVERY FURNACE
WATER
STEAM
GREEN LIQUOR
RECOVERED LIQUOR
MULTIPLE EFFECT EVAPORATOR
LIME
CAUSTICIZING
RECOVERED LIME
LIME KILN
FILTERS
SETTLING TANK
MUD
WHITE LIQUOR STORAGE

Figure 1. Process flow diagram-black liquor recovery

13. Strong black liquor is burned in the recovery furnace. Heat generated by the combustion of organic constituents is used to generate steam in a recovery boiler. This steam is returned to the plant and can be used directly in the process or to generate electricity.

14. The solid smelt removed from the recovery furnace is dissolved in water to form green liquor. This liquor is subjected to a causticizing treatment with slaked lime, to convert sodium carbonate to sodium hydroxide.

15. Following Step 14, the causticized liquor, referred to as "white liquor", is conveyed to a settling tank. Calcium carbonate sludge settles out in the tank and the white liquor is further clarified by filters. The clarified liquor is now ready for reuse as cooking liquor in the digester. The calcium carbonate sludge is burned in a lime kiln where carbon dioxide is liberated yielding calcium oxide or lime. This lime is reused in the causticizing of green liquor as in Step 14. The subject of these lime kilns as an emission source is covered in depth in a separate report entitled, "Air Pollution Control Technology and Costs in Seven Selected Areas". This report was prepared under EPA Contract No. 68-02-0289.

It is obvious from the preceding process description and flow diagram that the recovery system is an important part of the whole process. The recovery steps regenerate 95% of the chemicals used in addition to producing 10,000 lb steam[2] per ton of pulp produced. It is estimated[2] that in 1960, the pulp industry in the United States internally generated about 60% of the 30 billion Kw-hr of electrical energy that it consumed that year.

THE RECOVERY FURNACE

In the recovery furnace, combustion of black liquor is effected by spraying the atomized liquid onto the furnace walls. Spray nozzles are located on one furnace wall and oscillate (and/or rotate) automatically such that the sheet spray covers the remaining walls. The extent and frequency of oscillation is manually adjustable over a wide range in order to compensate for changes in solids content of the liquor. The adjustability permits optimization of the operation in terms of recovering cooking chemicals, disposing of organic sulfur compounds, satisfying process steam demand, and minimizing the quantity of objectionable emissions. In the lower portion of the furnace, called the reduction zone, inorganic sodium sulfate and sodium carbonate are reduced. These settle out in a smelt on the furnace grate. Organic sulfur compounds are oxidized in the upper, or oxidizing, zone.

Varying firing rates and steam demand affects the nature and quantity of pollutants emitted. An inadequate supply of primary or secondary air results in incomplete combustion giving rise to higher emission rates for carbon monoxide and other unburned hydrocarbons. Gaseous, malodorous components of the flue gas are hydrogen sulfide, mercaptans (particularly methyl mercaptan), dimethyl sulfide, dimethyl disulfide, and other organic sulfides and disulfides.

The odor problem in the vicinity of kraft pulp mills is aggravated by the fact that olfactory responses to gases mentioned in the preceding paragraph occur at extremely low concentrations. Hydrogen sulfide, for example, characterized by the smell of rotten eggs, has an odor threshold value in the parts per billion range. By contrast, the odor threshold for ammonia is over 50 parts per million. Table 4 lists ranges of odor threshold values for some of these gases along with their characteristic odor[3].

NATURE OF THE GASEOUS DISCHARGE

The nature of the gas discharged from the black liquor recovery system strongly depends upon which of several alternative flow schemes is used. The conventional scheme is the one shown in Figure 2. The black liquor is concentrated from 15% to about 50% dissolved solids in a series of multiple effect evaporators. It is then pumped from storage through the wet bottom of the precipitator, if used, where the salt cake collected by the precipitator is deposited and dissolved into the liquor. From this point, it goes to the chemical ash tank where it receives the salt cake that accumulates in the hoppers under the boiler section of the recovery boiler. From the chemical ash tank the liquor goes to a direct contact evaporator. This evaporator may be either a cyclone or cascade type. In either case, the liquor is in direct contact with the flue gases from the boiler. The flue gases enter the evaporator at about 550°F, leave at about 300°F, and pick up enough water from the liquor to concentrate it to 63%+ solids. From the evaporator, the liquor goes to the salt cake mix tank where make-up salt cake is added as required before it goes to the burner nozzles in the recovery furnace.

The conventional system has two sources of odor emission: the furnace and the direct contact evaporator. If the furnace is operated properly at its design rating, with sufficient combustion air, it should not be a significant source of odor[6]. The tendency, however, is to run these furnaces well above capacity. Under these conditions, emissions of odorous gases occur at a much higher rate, as illustrated in Figure 3[1].

Odorous emissions occur at the direct contact evaporator due to chemical reactions between components of the black liquor and the furnace flue gases.

TABLE 4[3]

ODOROUS CHEMICALS EMITTED FROM KRAFT PULP MILLS

Gaseous Compound	Odor Threshold Range ppm by Volume	Characteristic Odor
Sulfur Dioxide	1.0 to 5.0	Sharp, pungent
Hydrogen Sulfide	0.0009 to 0.0085	Rotten eggs
Methyl Mercaptan	0.0006 to 0.040	Rotten cabbage
Dimethyl Sulfide	0.0001 to 0.0036	Vegetable sulfide

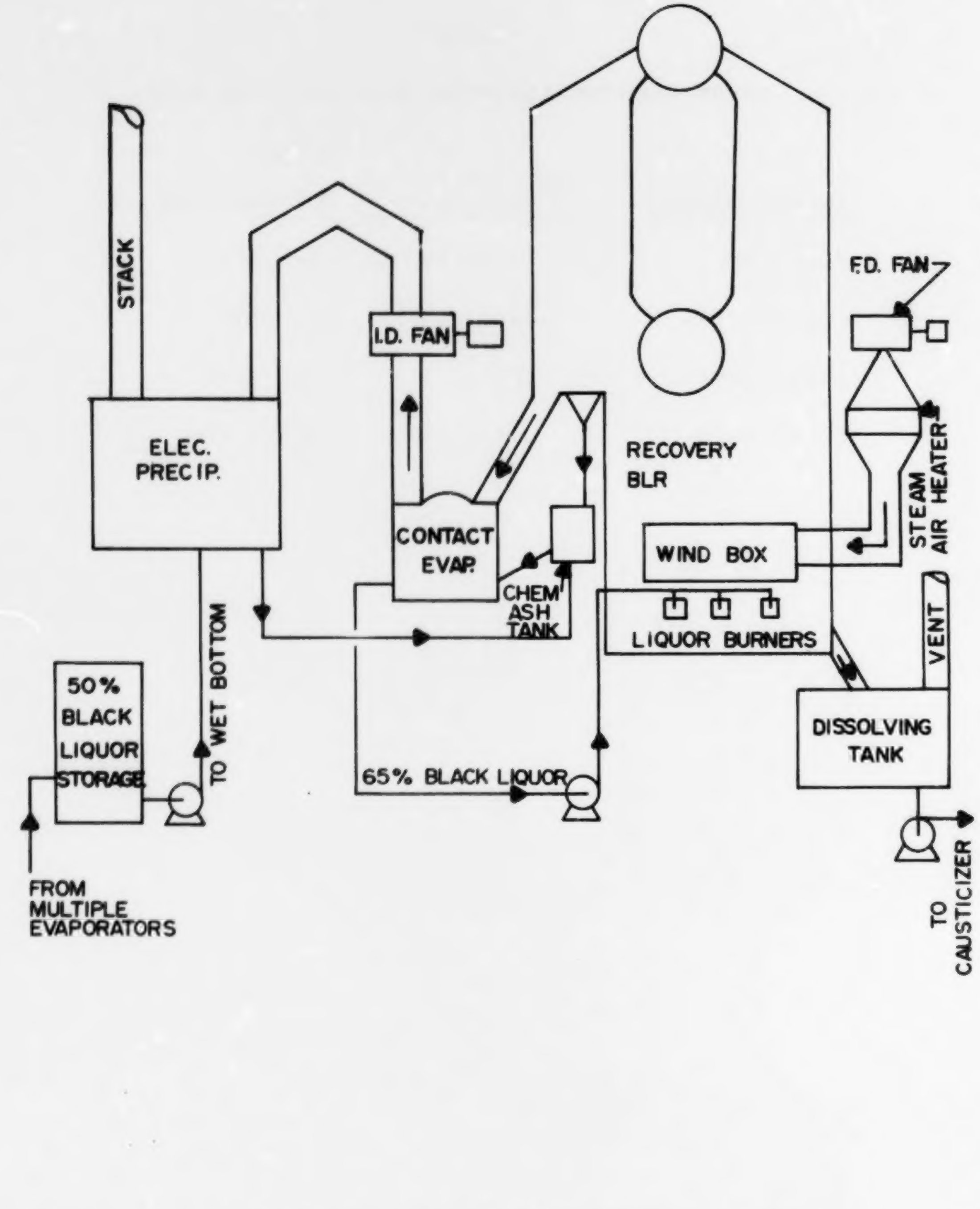

STACK
I.D. FAN
ELEC.
PRECIP.
CONTACT
EVAP.
CHEM
ASH
TANK
RECOVERY
BLR
F.D. FAN
STEAM
AIR HEATER
WIND BOX
LIQUOR BURNERS
VENT
DISSOLVING
TANK
50%
BLACK
LIQUOR
STORAGE
TO WET BOTTOM
65% BLACK LIQUOR
FROM
MULTIPLE
EVAPORATORS
TO
CAUSTICIZER

Figure 2. Flow diagram of conventional recovery furnace.

$$Na_2S + 2H_2O \rightarrow 2NaOH + H_2S$$

$$Na_2S + CO_2 + H_2O \rightarrow Na_2CO_3 + H_2S$$

Exhaust gases from recovery boilers using direct contact evaporators have been reported to contain 70 to 1,500 ppm of H_2S[9] and constitute the principal source of odor from recovery boilers not using oxidized black liquor[8].

As well as concentrating the black liquor, the direct contact evaporator performs an efficient job as a SO_2 scrubber, and a limited and rather less efficient job as a particle collector. Particulate loadings from recovery boilers having direct contact evaporators, not using venturi scrubbers, will range from 1.5 gr/ACF to 3.0 gr/ACF. Exit flue gas temperatures will range from 270°F to 350°F.

Several alternative approaches to the conventional flow scheme have been tried in order to reduce the emissions of odorous gases. Each of these schemes has been aimed at impeding the mechanisms by which odorous gases are formed in the direct contact evaporator.

Three different process schemes have been put forward to alter the chemistry in the evaporator. The first of these is to precede the evaporator step with an oxidation step.

Oxidation

The oxidation reaction converts Na_2S to $Na_2S_2O_3$ and, as a result, Na_2S is not available for hydrolysis or reaction with CO_2, and H_2S is therefore not formed. Black liquor oxidization to the extent of 99% and higher is commercially feasible[3].

The weak or strong black liquor, or both, may be oxidized. However, reverse reactions yielding Na_2S are possible and can impede overall effectiveness. Where a low cost source of O_2 is available, weak liquor oxidation can be done very efficiently and with a minimum of capital equipment. Since foaming of the oxidized black liquor in the recovery furnace is a problem with weak liquor, strong liquor oxidation is used more often.

A block flow diagram of this process is presented in Figure 4.

ACE System

Another process which alters the chemistry in the evaporator uses an air contact evaporator and is called the ACE system. A regenerative air heater replaces the direct contact evaporator on the flue gas end of the boiler. The heated combustion air from the air heater is then used to evaporate the water, and thus concentrate

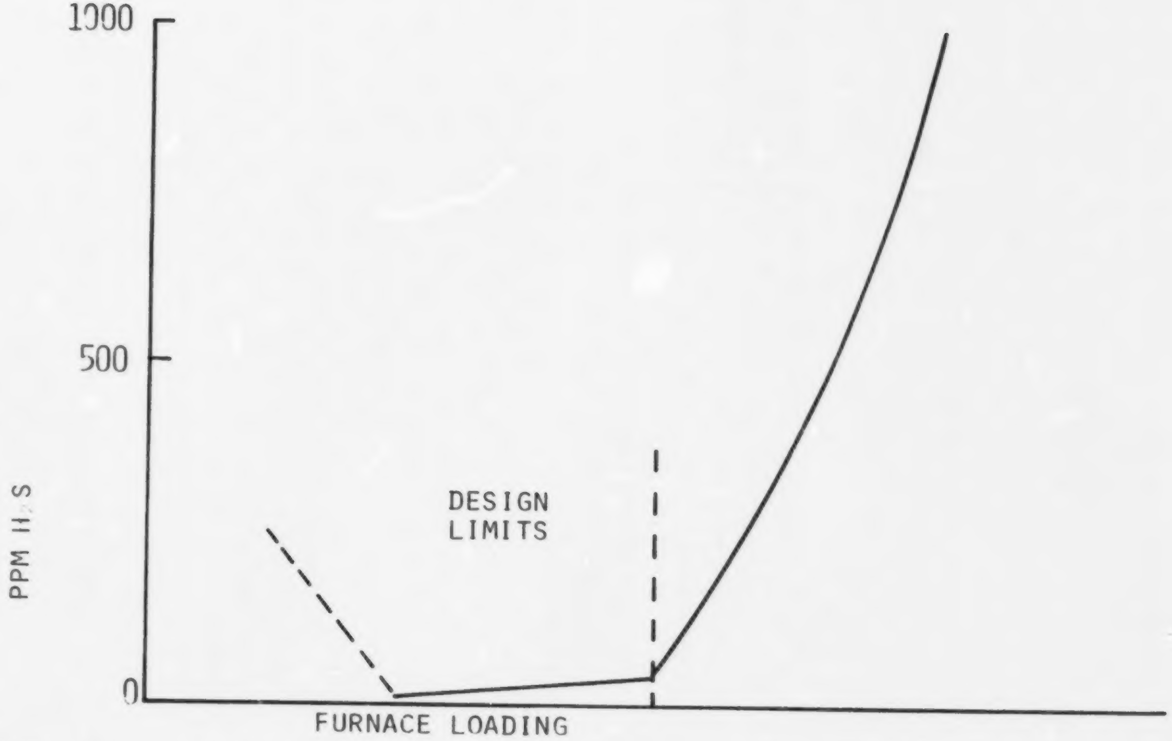


Figure 3. Relation between H_2S production and furnace loading.

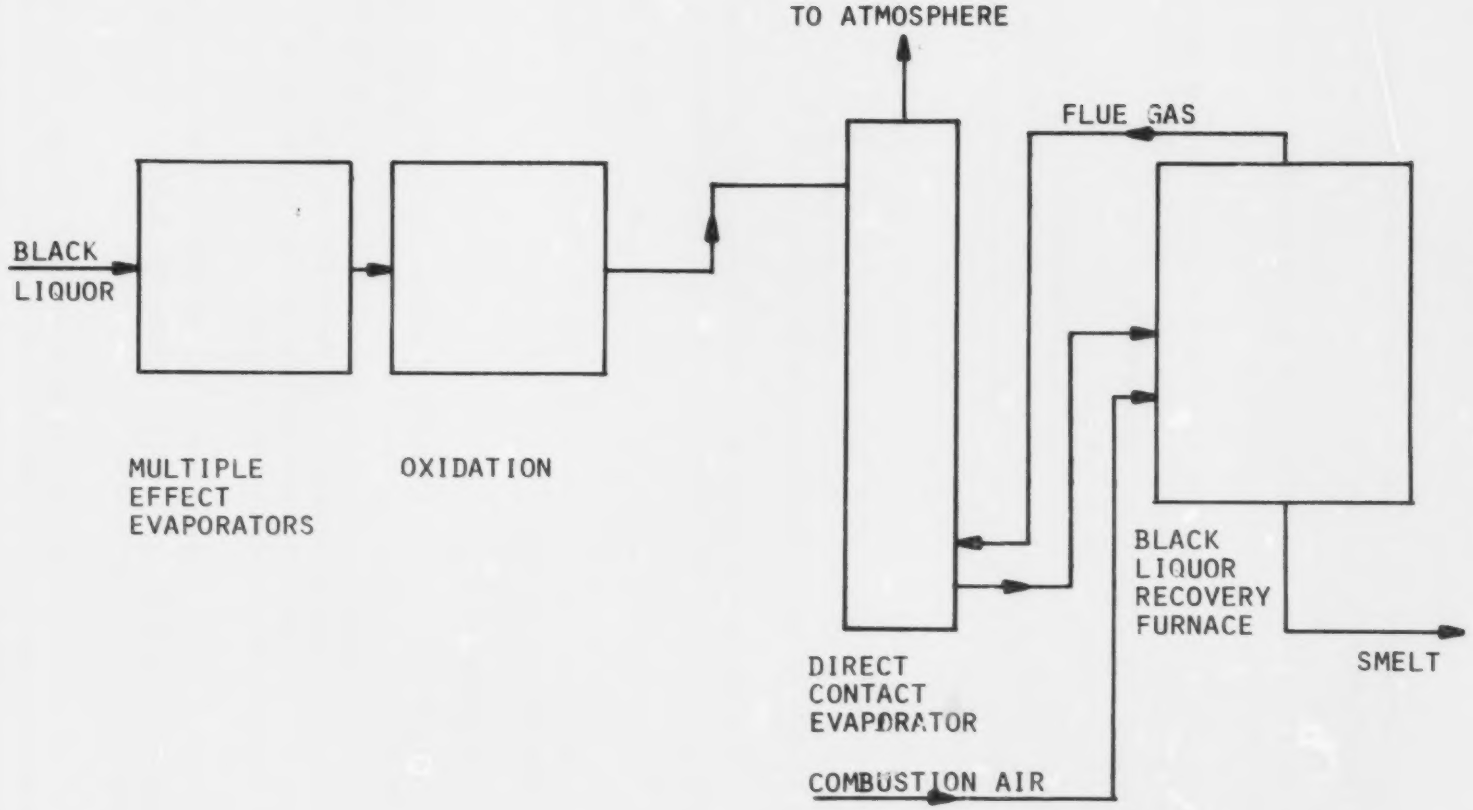

TO ATMOSPHERE
FLUE GAS
BLACK LIQUOR
MULTIPLE EFFECT EVAPORATORS
OXIDATION
DIRECT CONTACT EVAPORATOR
BLACK LIQUOR RECOVERY FURNACE
SMELT
COMBUSTION AIR

Figure 4. Black liquor recovery using oxidation, block flow diagram.

the liquor for firing into the furnace, in a cascade type contact evaporator before the air is directed to the wind boxes of the furnace. Since the CO_2 in the flue gases does not come in direct contact with the Na_2S in the liquor, no H_2S is formed. This process, however, does not prevent the production of H_2S by the hydrolysis route. A flow diagram is shown in Figure 5.

Since the flue gases from the boiler also pass through the small passages of the air heater, there is a tendency for these passages to plug, and they must be kept clean by soot blowing and periodic washing.

During at least part of the washing period, the air heater must be isolated from the system by means of gates, to prevent water carry-over. These boilers have two air heaters so that it is possible for the boiler to remain in service while one heater is being washed.

Controlling the combustion of liquor presents some problems with this system, due to the high moisture content of the combustion air, which results from the evaporation of water from the liquor in the air cascade evaporator. The level of SO_2 emission is generally higher than with the conventional system.

This system does not require black liquor oxidation to control H_2S emission, nor does it require a black liquor concentrator following the multiple effect evaporators.

The particulate loadings from this type of recovery boiler system will range from 2.5 gr/ACF to 4.5 gr/ACF. The salt cake collected in the precipitator appears to be more sticky than that found in other systems. Exit flue gas temperature will range from 325°F to 400°F.

LAH System

The Laminaire air heater (LAH) type of boiler arrangement is similar to the ACE system since it utilizes regenerative air heaters. However, it does not have an air contact evaporator. A flow diagram is shown in Figure 6. With the exception of the furnace, which is designed to burn black liquor, the boiler arrangement is very much like most utility boilers. Means are provided for washing one of the two air heaters while the boiler remains in service.

Since a contact evaporator is not used, the liquor from the multiple effect evaporators must be further concentrated to about 63% solids in a steam concentrator, before it can be fired in the furnace.

Particulate loading will range from 3.0 to 4.5 gr/ACF. Flue gas temperatures generally will range from 350°F to 400°F. Flue gas volumes, as with the ACE system, will average higher than with other systems due to the leakage in the air heater. Seals must be maintained in order to keep this leakage at a minimum.

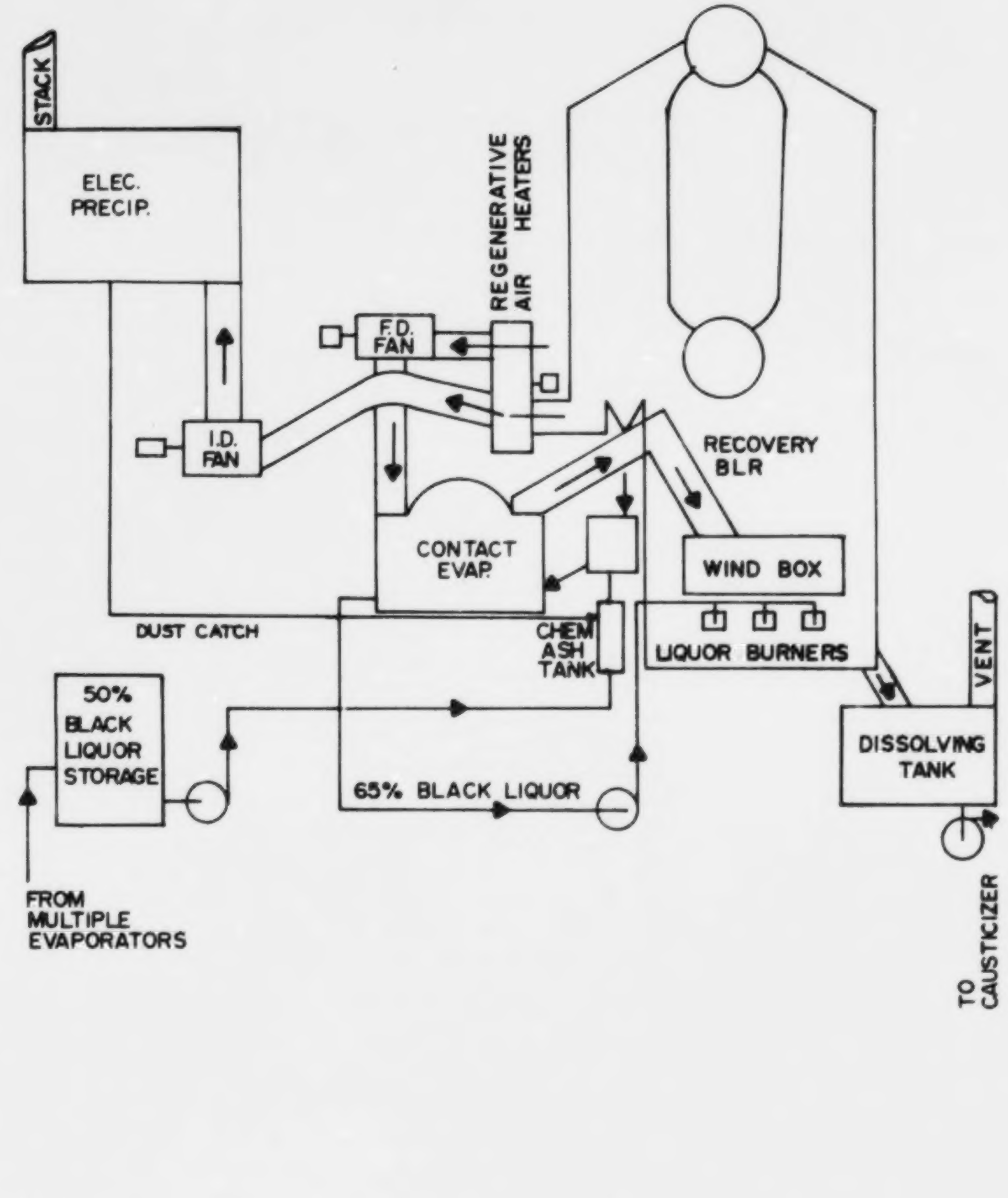

STACK
ELEC. PRECIP.
REGENERATIVE AIR HEATERS
F.D. FAN
I.D. FAN
RECOVERY BLR
CONTACT EVAP.
WIND BOX
DUST CATCH
CHEM ASH TANK
LIQUOR BURNERS
VENT
50% BLACK LIQUOR STORAGE
DISSOLVING TANK
65% BLACK LIQUOR
FROM MULTIPLE EVAPORATORS
TO CAUSTICIZER

Figure 5. Flow diagram of air contact evaporation system.

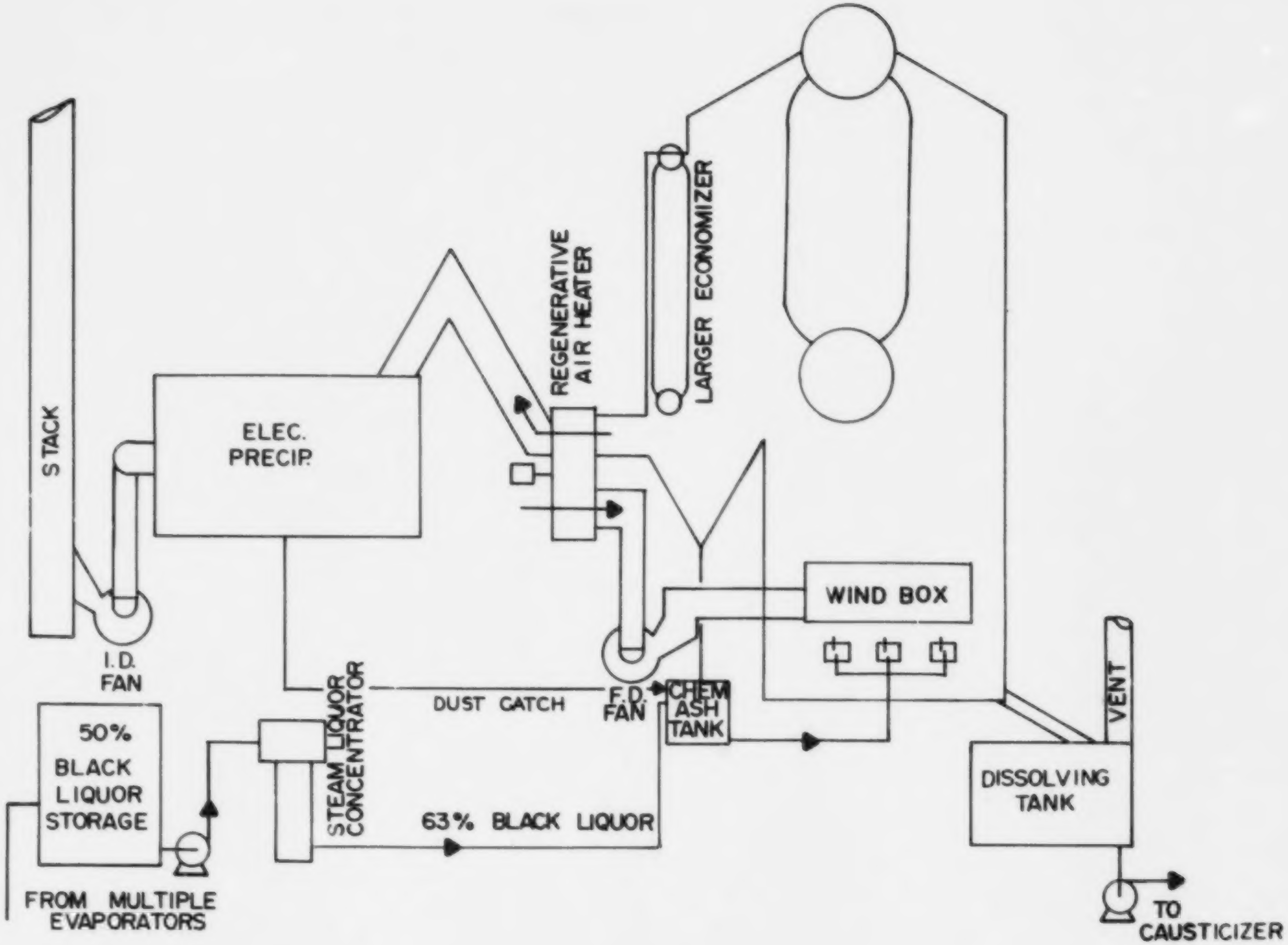

STACK
ELEC. PRECIP.
REGENERATIVE AIR HEATER
LARGER ECONOMIZER
WIND BOX
I.D. FAN
F.D. FAN
CHEM ASH TANK
DUST CATCH
VENT
DISSOLVING TANK
50% BLACK LIQUOR STORAGE
STEAM LIQUOR CONCENTRATOR
63% BLACK LIQUOR
FROM MULTIPLE EVAPORATORS
TO CAUSTICIZER

Figure 6. Flow diagram of Laminaire air heater system.

Large Economizer

The large economizer boiler arrangement does not utilize a contact evaporator and therefore the liquor must be concentrated before firing, as with the LAH arrangement. This has been achieved by designing the multiple effect evaporators to produce 60 to 63% solids content product and recovering available furnace heat from the flue gases with a large economizer. A flow diagram of this arrangement is shown in Figure 7. The size and configuration of the economizer will depend upon the desired feed water temperature and flue gas temperature requirement.

Since there is a tendency for the economizer to plug, soot-blower steam requirements are considerable and account for the higher than expected water vapor in the flue gas along with its volume. Particulate loading will range from 3.0 to as high as 6.0 gr/ACF, with exhaust temperatures from 350°F to 450°F. Grain loading, as well as temperature, tend to cycle with the cleanliness in the economizer. As the economizer becomes dirty, the exit gas temperature will go up. The grain loading in the flue gas will sharply increase when the blower cycle begins.

NATURE OF THE PARTICULATE EMISSION

Particulate emissions from a kraft recovery furnace are characterized by a high sodium content. A small percentage of these particles may be as large as 10 microns in diameter but, generally, they will be smaller than 1 micron.

Most of the salt cake fired into the furnace with the black liquor is reduced to sodium sulfide and is removed from the furnace as smelt. A portion of the salt cake volatilizes and passes through the boiler where it condenses on cooler surfaces or in cooler gases. Particulates formed in this manner are extremely small in size, generally below one micron.

The control of air to the furnace is very important. Excess air in the reduction zone will oxidize carbon directly to carbon dioxide, destroying its ability to reduce salt cake to sodium sulfide. If excess air is reduced, the concentration of sodium carbonate in the carry-over will increase. The condition of the smelt bed and its temperature will also have an effect on the particulate matter as well as the gases emitted.

Some of the salt cake will collect in the generating tube, superheater tube, and economizer tube sections of the boiler. This is removed by automatic soot blowers and in some cases lancing. Much of this is reentrained in the gas stream and leaves the boiler with the flue gases. The remainder is collected in hoppers under the economizer and returned to the chemical ash tank where it is put back into the black liquor. Since the bulk density of the salt cake leaving

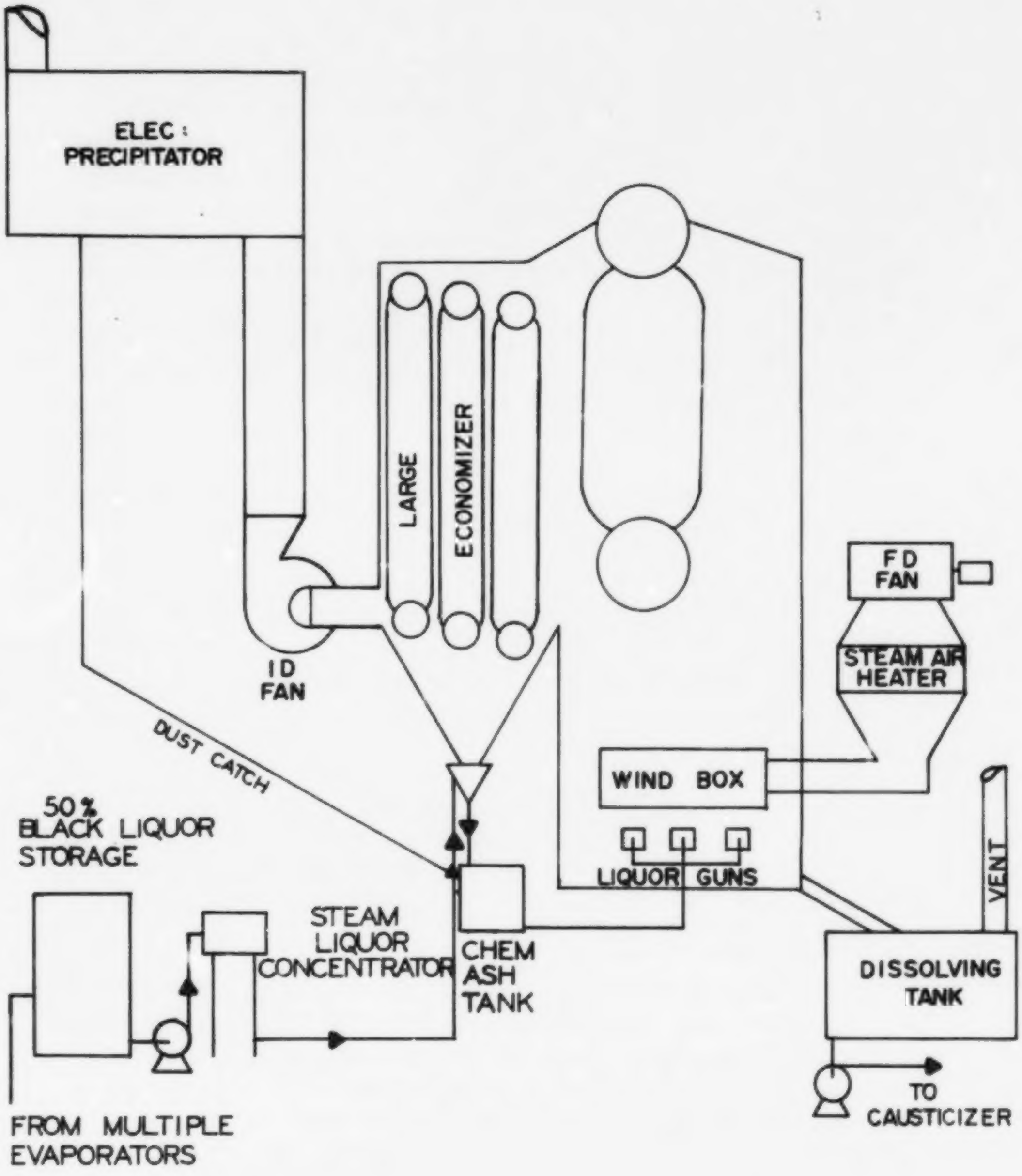

ELEC :
PRECIPITATOR
LARGE
ECONOMIZER
ID
FAN
FD
FAN
STEAM AIR
HEATER
DUST CATCH
WIND BOX
50%
BLACK LIQUOR
STORAGE
LIQUOR GUNS
VENT
STEAM
LIQUOR
CONCENTRATOR
CHEM
ASH
TANK
DISSOLVING
TANK
TO
CAUSTICIZER
FROM MULTIPLE
EVAPORATORS

Figure 7. Flow diagram of large economizer system.

the boiler is well below 10 lbs/cu/ft, it is very easily reentrained.

The quantities of particulates emitted, including sodium sulfate, sodium carbonate, and unburned carbon will be in the range of 90 to 275 pounds per air dried ton (ADT) of pulp produced by the plant. A nominal average emission rate of 150 lb/(ADT)[2, 4] is used for estimating purposes. This loss of chemical is not only an economic problem to the plant (sodium sulfate lost must be replaced in the process) but is also an air pollution nuisance.

POLLUTION CONTROL CONSIDERATIONS

Early methods of reducing particulate emission consisted of filters, using wetted wood chips and cyclone type mechanical collectors. Later, these were replaced with electrostatic precipitators and wet scrubbers, both capable of 90% collecting efficiency. Precipitators were capable of still higher efficiency, but the increased efficiency above 90% could not be economically justified. At this efficiency, and assuming the uncontrolled plant would emit 150 lb of salt cake per (ADT) of pulp produced, there would be a net reclamation of 135 lb of salt cake. Using a delivered cost of salt cake of $0.015/lb, the reclaimed chemicals produce a savings of over $2.00 per (ADT).

Scrubbers are no longer employed as a primary collector. The scrubbers used were high energy venturi types using black liquor as the scrubbing media which provided a means of heat recovery. The black liquor was concentrated by evaporation as it cooled the flue gas to about 180°F. The black liquor, used as scrubbing media, however, was in direct contact with the flue gases and became another source for odor pick-up. Foaming is also a problem.

Scrubbing is effective in the removal of both particulate and gaseous emissions, particularly SO_2 where black liquor is used. The overall thermal efficiency of a furnace equipped with a venturi-evaporative scrubber is considerably higher than a comparable furnace employing an electrostatic precipitator since the final discharge gas temperature is 120°F lower in the former case. In order to obtain the 90% collecting efficiency, the pressure drop across the venturi has to be maintained at about 40 in.wc.

Low energy water scrubbers are being currently used following some precipitators to collect agglomerates which have been re-entrained. These agglomerates are large particles, or flakes of salt cake, which are relatively flat, presenting a high sail area for re-entrainment after initial collection. The emission of these re-entrained particles is known as "snowing". In some cases, where the scrubber is not actually provided as part of a new emission control system, provisions are made for future addition of these scrubbers.

Today, precipitators are the sole device being purchased for the control of particulate emission from recovery boiler gases. Recently installed units and those currently contemplated are all designed at efficiencies ranging from 99.5% to 99.9%. Boilers without contact evaporators generally have a slightly higher inlet dust loading and, therefore, the precipitator should be designed for a higher efficiency in order to yield the same residual. All of the precipitators have steel shells and are well insulated. In some instances, auxiliary heat is supplied between the insulation and the shell. Each unit is designed with many bus sections and always has two or more chambers. Electronic automatic controls maintain the operating level, so little or no attention is required of the plant operators.

Although there are now no commercial kraft installations employing fabric filters, the economics of this abatement method are becoming more attractive. There is ongoing pilot plant work on kraft mill fabric filters and it is expected that a prototype will be built soon.

SPECIFICATIONS AND COSTS

Equipment specifications were written for electrostatic precipitators applied to both conventional and controlled odor (large economizer) type recovery boilers. Each specification requested costs for both medium and high efficiency performance precipitators applied to a small (500 ADT/day of pulp) and a large (1,500 ADT/day pulp) recovery boiler. Medium efficiency was specified at a residual of 1.7 lb. of emission/ADT.* High efficiency was specified at 0.02 gr/DSCF. These specifications are shown in Tables 5, 6, 9, 10, 11, and 12.

Two sets of specifications were written for the controlled odor boiler cases: one specifying a roof location for the precipitator, the other specifying a ground location. Some of the bidders reported no difference in capital cost between the two systems. Other bidders reported differences as summarized below.

	Additional Cost for Ground Location	
Boiler Size	Dollars	% of Total Capital Cost
Small	$210 M	11
Large	$640 M	14

---

*While the paper industry and old pollution control codes quantify emissions in terms of lbs/ADT, equipment manufacturers use gr/ACF.

As can be seen, the costs are greater for the ground locations. The ground locations cost the same amount more than the roof locations for both the medium and high efficiency precipitators since the increased cost is due solely to the additional structural steel and ductwork required for the ground location.

Cost data are presented for the conventional boiler in Tables 7 and 8 and in Figures 8, 9, 10, and 11. Cost data are presented for the controlled odor boiler (ground location) in Tables 9 and 10 and in Figures 12, 13, 14, and 15. Average drift velocities used to size the precipitators are summarized below.

	Drift Velocity	
	cm/sec	ft/sec
Conventional Boilers	7 to 8	0.23 to 0.26
Controlled Odor Boiler	5.51 to 6.5	0.18 to 0.21

The lower drift velocities in the controlled odor precipitators are due to lower particle density and size from the controlled odor boilers. The specifications for both types of boilers required that provision be made for a low energy "anti-snow" scrubber to be installed potentially at a later date. One precipitator bidder was asked to supply the cost of the scrubber that would be installed, should it be required. Those installed scrubber costs are estimated to be:

Small Plant (Med. and High Eff.) — $146,000
Large Plant (Med. and High Eff.) — $498,750

TABLE 5

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR CONVENTIONAL KRAFT PULP MILL RECOVERY FURNACE SPECIFICATION

A wet bottom electrostatic precipitator is to remove solids from the effluent gas from a new, conventional recovery furnace.

The system shall be quoted complete including all of the following:

1. *Inlet ductwork and inlet plenum.*
2. *Wet bottom electrostatic precipitator and liquor handling equipment.*
3. *Outlet ductwork and 100 foot stack.*
4. *Dampers, slide gates and pressure control system. The draft fan will be considered part of the boiler and will be supplied by others.*
5. *Other necessary auxiliary equipment.*
6. *Electrical installation work including only low voltage wiring.*

The precipitator is to continually reduce the solids content of the flue gas to the levels specified.

1. *Inlet Ductwork and Inlet Plenum*

   The outlet ductwork of the boiler will be extended through the roof by the boiler manufacturer and be available for connection to the inlet plenum of the precipitator. The inlet plenum will be specified.

2. *Precipitator*

   The precipitator shall be a wet bottom, single stage, plate type unit with a minimum of two fields in the direction of gas flow for the intermediate efficiency case and three fields for the high efficiency case. Inlet face velocity shall not exceed 5 FPS and 4 FPS, respectively.

   The precipitator shall be divided into two gas-tight chambers. Dampers or similar flow balancing devices shall be furnished for each chamber. Each chamber will have slide gates at inlet and outlet, so that one chamber may be isolated for repairs while the other chamber remains operative. A heated pressurized penthouse design should be employed. Shell heating is not required.

   The precipitator will be located on the roof of the recovery boiler building.

   The wet bottom shall be capable of holding a minimum depth of one foot of black liquor. Agitators will cover a minimum of 50% of the bottom area and will continuously mix deposited salt cake into the black liquor. One black liquor feed connection, one *overflow connection, one emergency overflow, three inch instrument flanged connection, and one drain connection will be provided. Black liquor handling to and from the precipitator will be supplied by others. The black liquor coming to the precipitator wet bottom will normally contain ≤67 wt% solid.*

Electrical power at 460v, 3 phase, 60 cycle; and 110v, 1 phase, 60 cycle is available in sufficient quantity at the site. Automatic voltage controls shall be provided for each field. A safety interlock system shall be provided so that no access to high voltage equipment is possible without first de-energizing all fields.

Equipment shall be provided for continuous removal of the solids recovered in the liquor. Storage equipment will have a capacity sufficient for 24 hours of continuous operation, and will be supplied by the purchaser.

3. *Outlet Ductwork and Stack*

The cleaned gases will be conveyed to the atmosphere by the outlet ductwork and stack, located on the roof. The outlet ductwork will be the equivalent of 150 linear feet and will have provisions for the addition of a wet scrubber at a later time.

4. *Fans, Dampers, and Pressure Control System*

A fan of sufficient size to overcome the pressure drop of the precipitator system, including possible future secondary wet scrubber, will be supplied by the boiler manufacturer. Appropriate dampers shall be placed so as to control the flow of gas as described in Section #2.

The material of construction of all parts of the system shall be mild steel.

A model study for the precipitator gas distribution system will not be required.

TABLE 6

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR CONVENTIONAL KRAFT PULP MILL RECOVERY FURNACE SPECIFICATION

	Small	*Large*
Plant Capacity, ADT/day	*500*	*1,500*
Precipitator Inlet Conditions		
Gas Rate, ACFM	*265,300*	*795,900*
Temperature, °F	*350*	*350*
Gas Rate, SCFM	*173,600*	*520,800*
Moisture Content, vol%	*30*	*30*
Gas Rate, DSCFM	*121,500*	*364,500*
Inlet Loading		
gr/ACF	*2.0*	*2.0*
gr/DSCF	*4.4*	*4.4*
lb/hr	*4,549*	*13,647*
Precipitator Outlet Conditions		
Gas Rate, ACFM	*265,300*	*795,900*
Temperature, °F	*350*	*350*
Gas Rate, SCFM	*173,600*	*520,800*
Moisture Content, vol%	*30*	*30*
Gas Rate, DSCFM	*121,500*	*364,500*
Residual, Med. Eff. Case		
gr/ACF	*0.016*	*0.016*
gr/DSCF	*.035*	*.035*
lb/hr	*36*	*109*
Collection Efficiency,%	*99.2*	*99.2*
Residual, High Eff. Case		
gr/ACF	*0.009*	*0.009*
gr/DSCF	*0.02*	*0.02*
lb/hr	*20.8*	*62.4*
Collection Efficiency,%	*99.6*	*99.6*

TABLE 7

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONVENTIONAL RECOVERY FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	265,300	795,900	265,300	795,900
°F	350	350	350	350
SCFM	173,600	520,800	173,600	520,800
Moisture Content, Vol. %	30	30	30	30
Effluent Contaminant Loading				
gr/ACF	2.0	2.0	2.0	2.0
lb/hr	4,549	13,647	2,549	13,647
Cleaned Gas Flow				
ACFM	265,300	795,900	265,300	795,900
°F	350	350	350	350
SCFM	173,600	520,800	173,600	520,800
Moisture Content, Vol. %	30	30	30	30
Cleaned Gas Contaminant Loading				
gr/ACF	.016	.016	.009	.009
lb/hr	36	109	20.8	62.4
Cleaning Efficiency, %	99.2	99.2	99.6	99.6
(1) Gas Cleaning Device Cost	469,367	1,097,288	534,121	1,372,041
(2) Auxiliaries Cost	55,973	112,350	73,334	133,744
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost	677,390	1,316,453	729,157	1,539,262
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost	1,202,730	2,526,092	1,336,613	3,045,047

TABLE 8

ANNUAL OPERATING COST DATA (COST IN $/YEAR) FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONVENTIONAL RECOVERY FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year-8600					
Operating Labor (if any)					
Operator	$6/mh	3,240	3,240	3,240	3,240
Supervisor	$8/mh	1,440	1,440	1,440	1,440
Total Operating Labor		4,680	4,680	4,680	4,680
Maintenance					
Labor	$6/mh	1,920	2,580	1,920	2,580
Materials		67	100	67	100
Total Maintenance		1,987	2,680	1,987	2,680
Replacement Parts		9,200	14,825	9,200	14,825
Total Replacement Parts		9,200	14,825	9,200	14,825
Utilities					
Electric Power	$0.011 kwh	42,100	113,400	45,800	123,700
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities		42,100	113,400	45,800	123,700
Total Direct Cost		57,967	135,585	61,667	145,885
Annualized Capital Charges	16% of Cap	192,437	404,175	213,858	487,208
Total Annual Cost		250,404	539,760	275,525	633,093

FIGURE 8

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT MILL CONVENTIONAL RECOVERY FURNACE (MEDIUM EFFICIENCY)

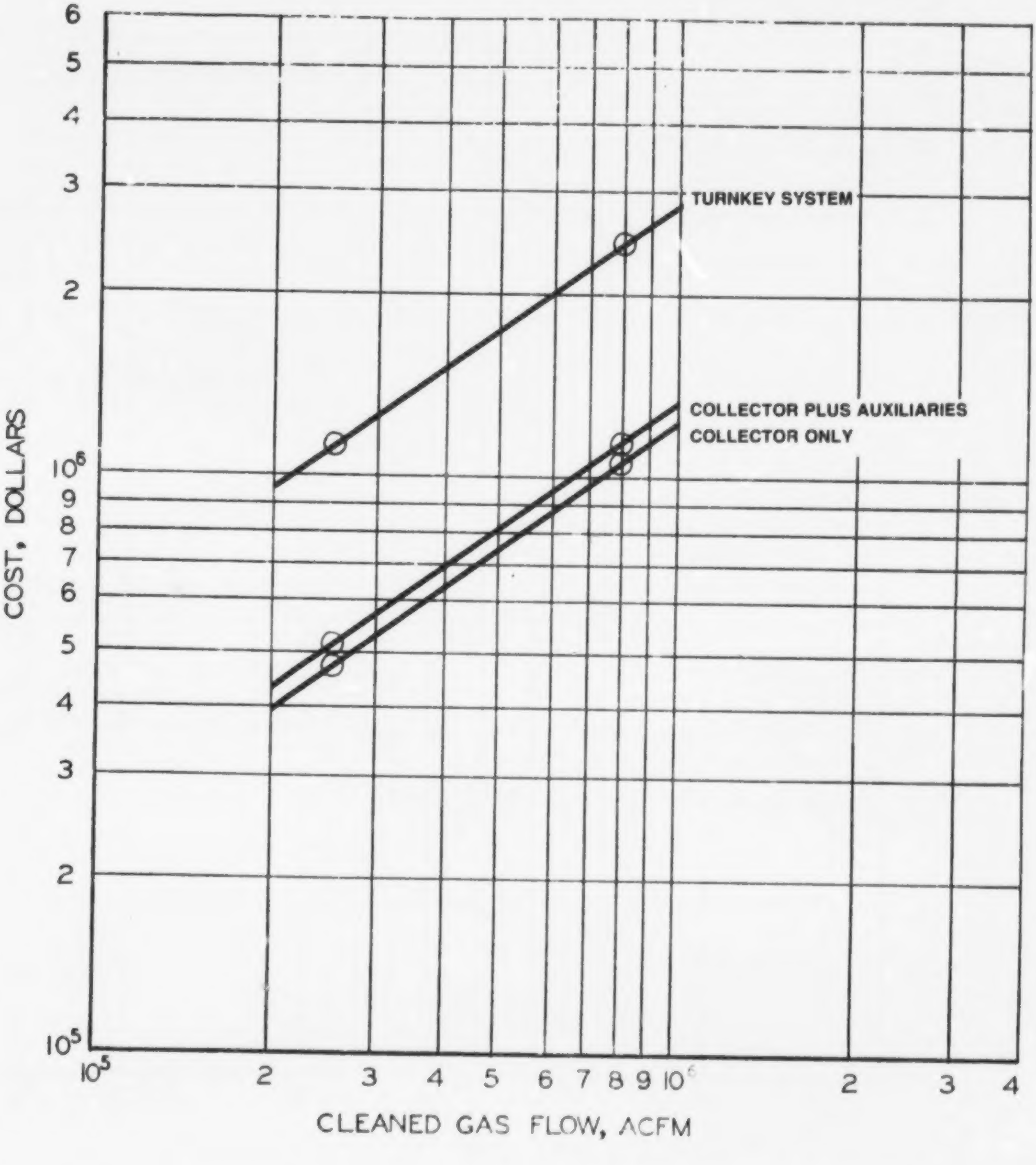


FIGURE 9

ANNUAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONVENTIONAL RECOVERY FURNACE (MEDIUM EFFICIENCY)

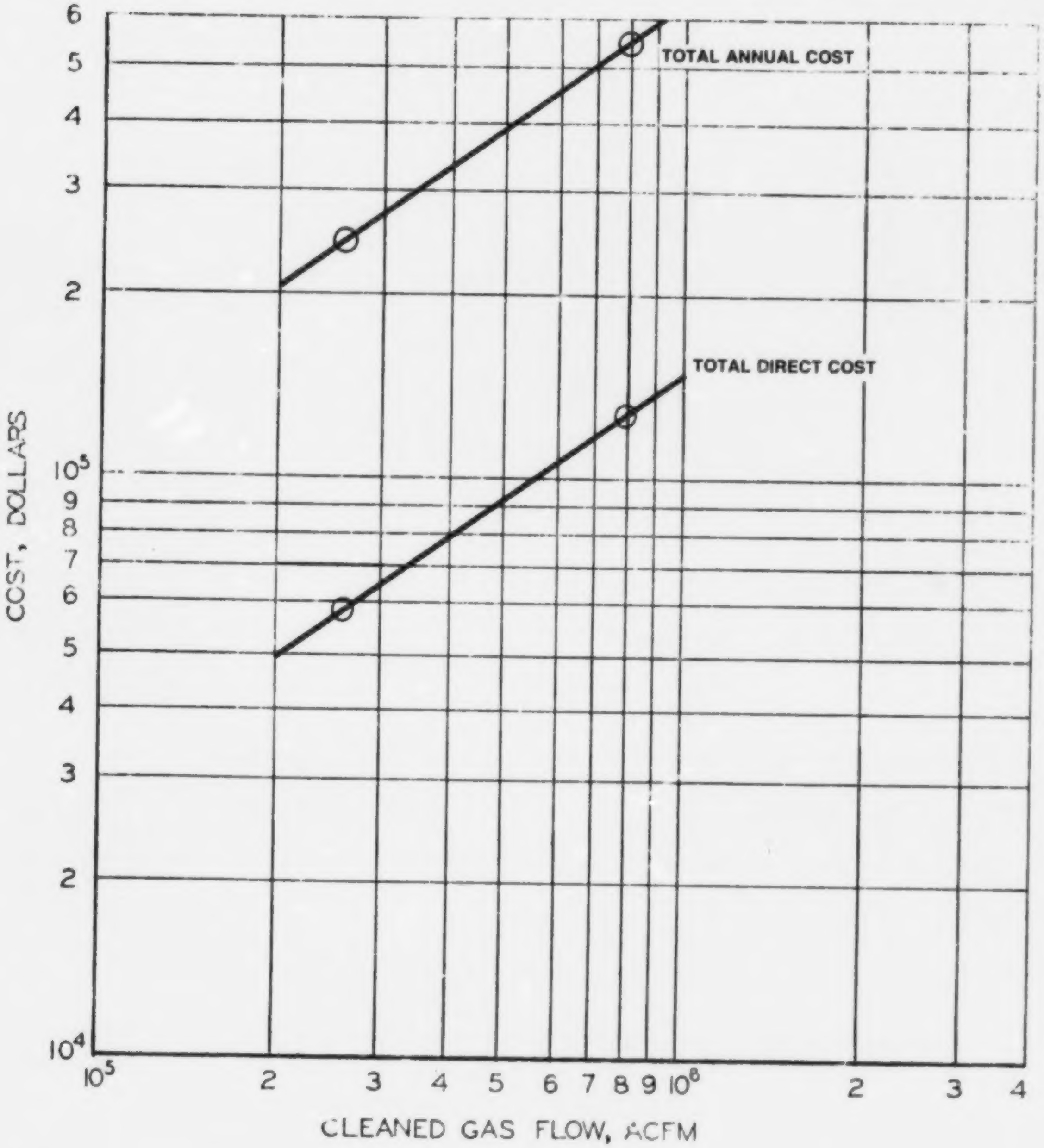


FIGURE 10

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONVENTIONAL RECOVERY FURNACE (HIGH EFFICIENCY)

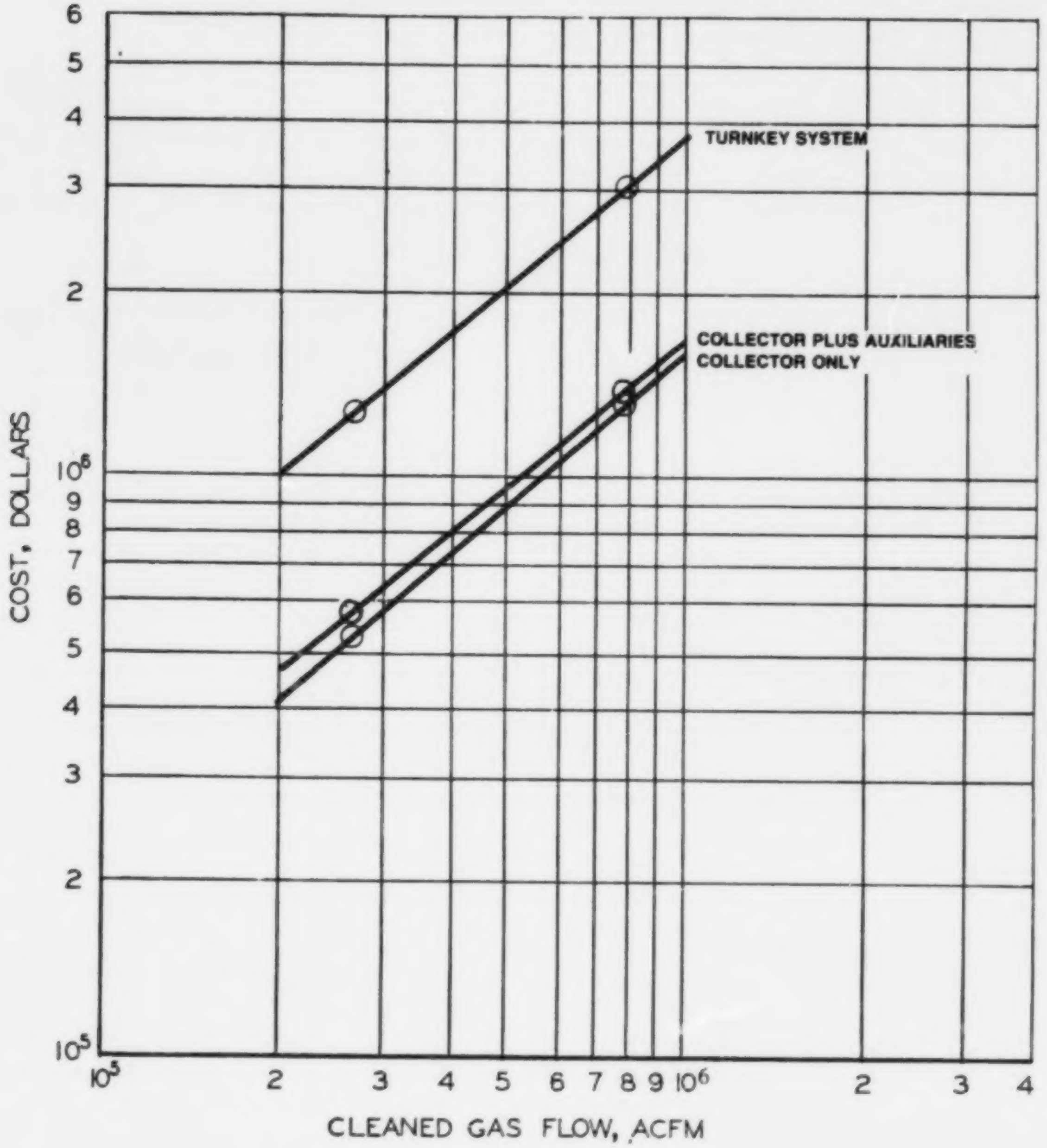


FIGURE 11

ANNUAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONVENTIONAL RECOVERY FURNACE (HIGH EFFICIENCY)

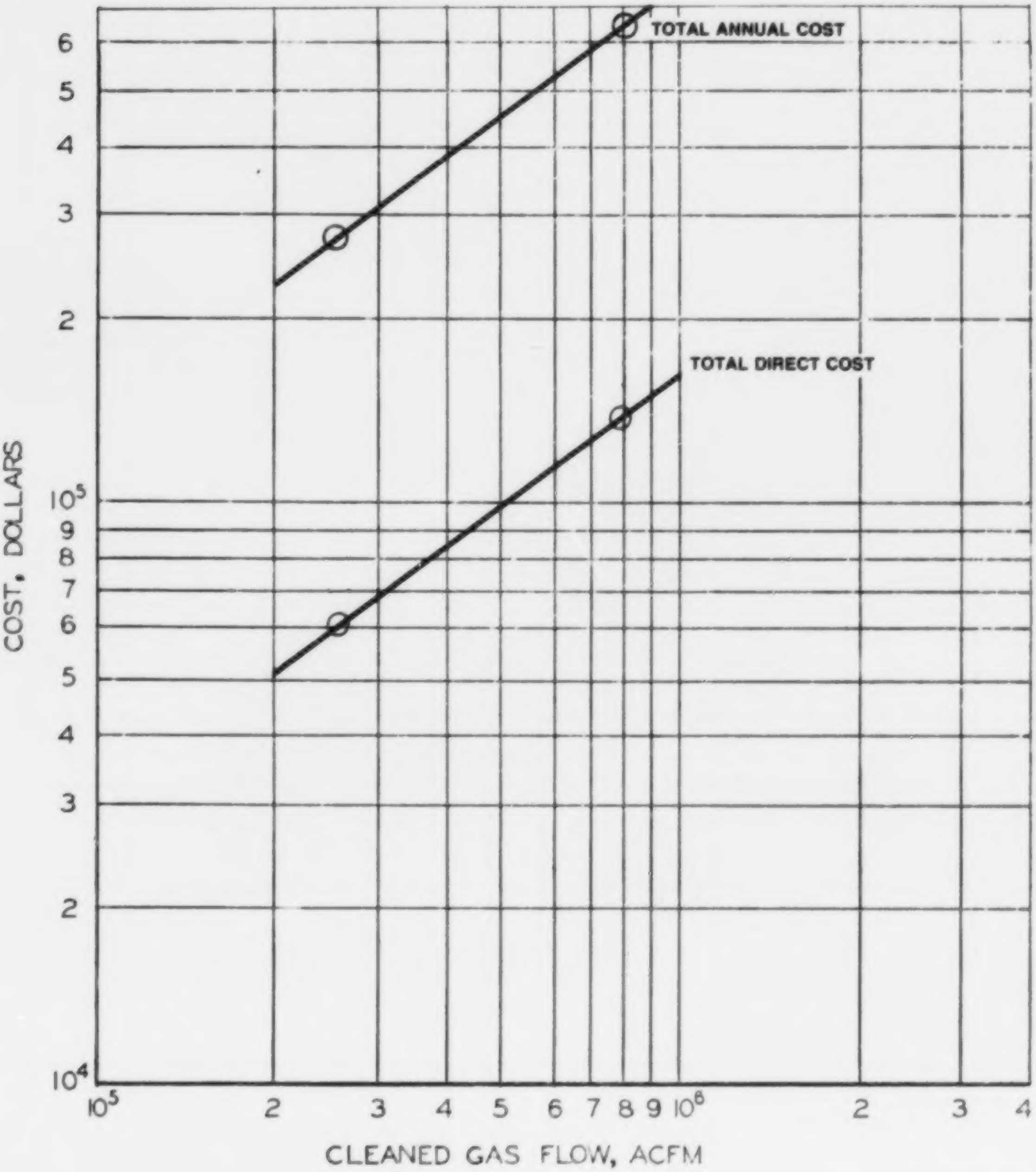


TABLE 9

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE SPECIFICATION

A dry bottom electrostatic precipitator is to remove solids from the effluent flue gas from a controlled odor recovery furnace.

The system shall be quoted complete including all of the following:

1. *Inlet ductwork and inlet plenum.*
2. *Dry bottom electrostatic precipitator.*
3. *Outlet ductwork and 100 foot stack.*
4. *Dampers, slide gates and pressure control system. The draft fan will be considered part of the boiler and will be supplied by others.*
5. *Other necessary auxiliary equipment.*
6. *Electrical installation work including only low voltage wiring.*

The precipitator is to continually reduce the solids content of the flue gas to the levels specified.

1. *Inlet Ductwork and Inlet Plenum*

   The outlet ductwork of the boiler will be extended through the roof by the boiler manufacturer and be available for connection to the inlet plenum of the precipitator. The inlet plenum will be specified.

2. *Precipitator*

   The precipitator shall be a wet bottom, single stage, plate type unit with a minimum of two fields in the direction of gas flow for the intermediate efficiency case and three fields for the high efficiency case. Inlet face velocity shall not exceed 4½ FPS and 4 FPS, respectively.

   The precipitator shall be divided into two gas-tight chambers. Dampers or similar flow balancing devices shall be furnished for each chamber. Each chamber will have slide gates at inlet and outlet, so that one chamber may be isolated for repairs while the other chamber remains operative. A heated pressurized penthouse design should be employed. Shell heating is not required.

   The precipitator will be located at ground level adjacent to the recovery boiler building.

   Electrical power at 460v, 3 phase, 60 cycle; and 110v, 1 phase, 60 cycle is available in sufficient quantity at the site. Automatic voltage controls shall be provided for each field. A safety system shall be provided so that no access to high voltage equipment is possible without first de-energizing all fields.

Equipment shall be provided for continuous removal of the solids recovered in the liquor. Storage equipment will have a capacity sufficient for 24 hours of continuous operation, and will be supplied by the purchaser.

3. *Outlet Ductwork and Stack*

   The cleaned gases will be conveyed to the atmosphere by the outlet ductwork and a stack located on the ground. The ductwork shall be the equivalent of 300 linear feet and will have provision for attachment of a secondary wet scrubber.

4. *Fans, Dampers, and Pressure Control System*

   A fan of sufficient size to overcome the pressure drop of the precipitator system, including possible future secondary wet scrubber, will be supplied by the boiler manufacturer. Appropriate dampers shall be placed so as to control the flow of gas as described in Section #2.

The material of construction of all parts of the system shall be mild steel.

A model study for the precipitator gas distribution system will not be required.

TABLE 10

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE SPECIFICATION

	Small	Large
Plant Capacity, ADT/day	500	1,500
Precipitator Inlet Conditions		
Gas Rate, ACFM	260,200	780,600
Temperature, °F	425	425
Gas Rate, SCFM	155,800	467,400
Moisture Content, vol%	22	22
Gas Rate, DSCFM	121,500	364,500
Inlet Loading		
gr/ACF	4.0	4.0
gr/DSCF	8.6	8.6
lb/hr	8,920	26,760
Precipitator Outlet Conditions		
Gas Rate, ACFM	260,200	780,600
Temperature, °F	425	425
Gas Rate, SCFM	155,800	467,400
Moisture Content, vol%	22	22
Gas Rate, DSCFM	121,500	364,500
Residual, Med. Eff. Case		
gr/ACF	0.016	0.016
gr/DSCF	0.080	0.080
lb/hr	36	107
Collection Efficiency,%	99.6	99.6
Residual, High Eff. Case		
gr/ACF	0.009	0.009
gr/DSCF	0.02	0.02
lb/hr	20.8	62.4
Collection Efficiency,%	99.8	99.8

TABLE 11

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	260,000	780,600	260,200	780,600
°F	425	425	425	425
SCFM	155,800	467,400	155,800	467,400
Moisture Content, Vol. %	22	22	22	22
Effluent Contaminant Loading				
gr/ACF	4.0	4.0	4.0	4.0
lb/hr	8,920	26,760	8,920	26,760
Cleaned Gas Flow				
ACFM	260,200	780,600	260,200	780,600
°F	425	425	425	425
SCFM	155,800	467,400	155,800	467,400
Moisture Content, Vol. %	22	22	22	22
Cleaned Gas Contaminant Loading				
gr/ACF	.016	.016	.009	.009
lb/hr	36	107	20.8	62.4
Cleaning Efficiency, %	99.6	99.6	99.8	99.8
(1) Gas Cleaning Device Cost	588,726	1,374,257	704,551	1,713,660
(2) Auxiliaries Cost				
(a) Fan(s)	94,065	213,764	98,909	227,347
(b) Pump(s)				
(c) Damper(s)	39,106	103,717	39,106	103,717
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost	863,120	1,936,340	943,358	2,172,809
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost	1,545,911	3,524,361	1,746,818	4,113,816

TABLE 12

ANNUAL OPERATING COST DATA (COST IN $/YEAR) FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year - 8600					
Operating Labor (if any)					
Operator	$6/mh	3,240	3,240	3,240	3,240
Supervisor	$8/mh	1,440	1,440	1,440	1,440
Total Operating Labor		4,680	4,680	4,680	4,680
Maintenance					
Labor	$6/mh	1,920	2,580	1,920	2,580
Materials		67	100	67	100
Total Maintenance		1,987	2,680	1,987	2,680
Replacement Parts		9,400	12,350	9,500	13,250
Total Replacement Parts		9,400	12,350	9,500	13,250
Utilities					
Electric Power	$0.011/kwh	45,800	125,600	46,400	127,900
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities		45,800	125,600	46,400	127,900
Total Direct Cost		61,867	145,310	62,567	148,510
Annualized Capital Charges	16% of Cap	247,346	563,898	279,491	658,211
Total Annual Cost		309,213	709,208	342,058	806,721

FIGURE 12

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE (MEDIUM EFFICIENCY)

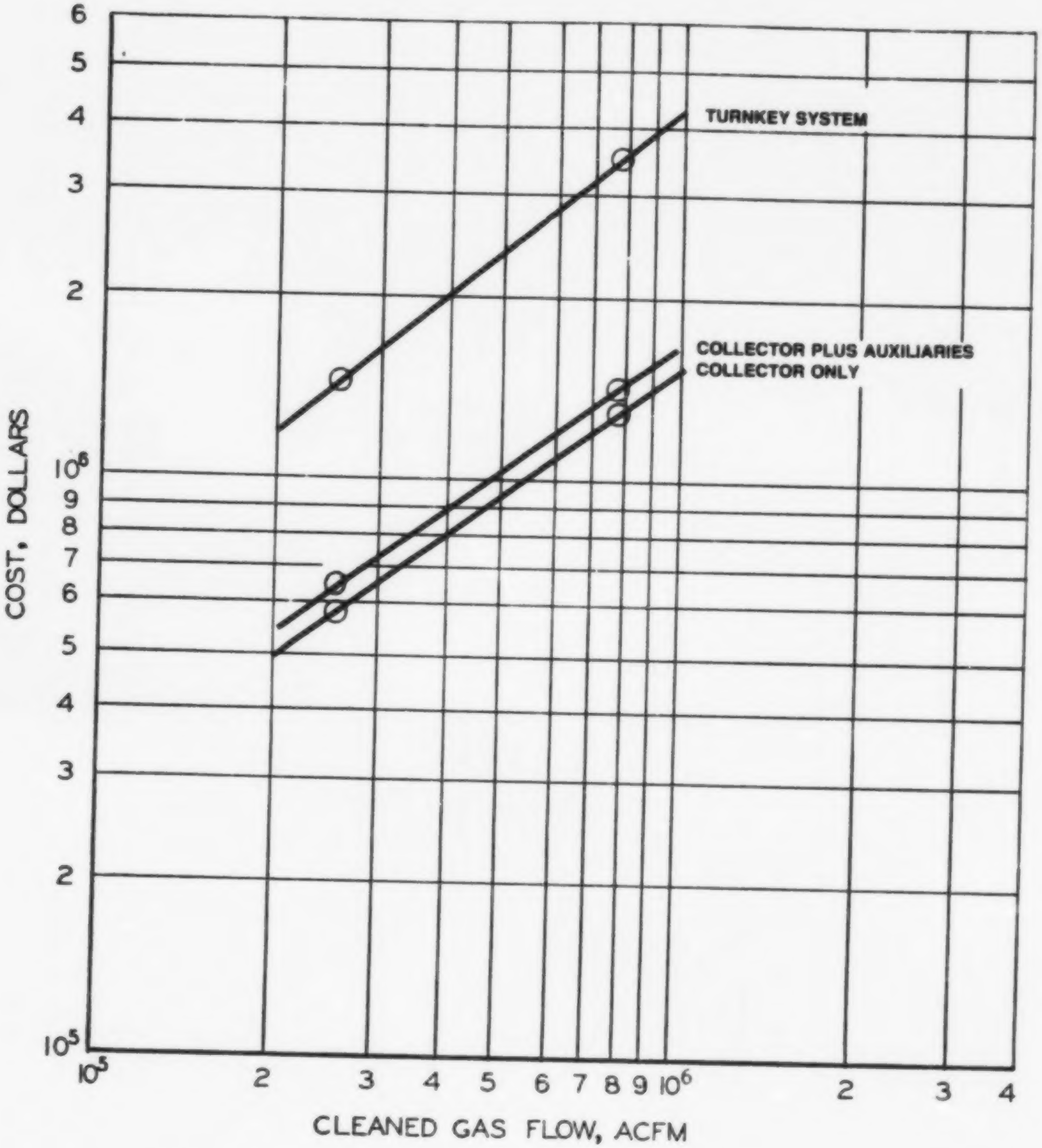


FIGURE 13

ANNUAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE (MEDIUM EFFICIENCY)

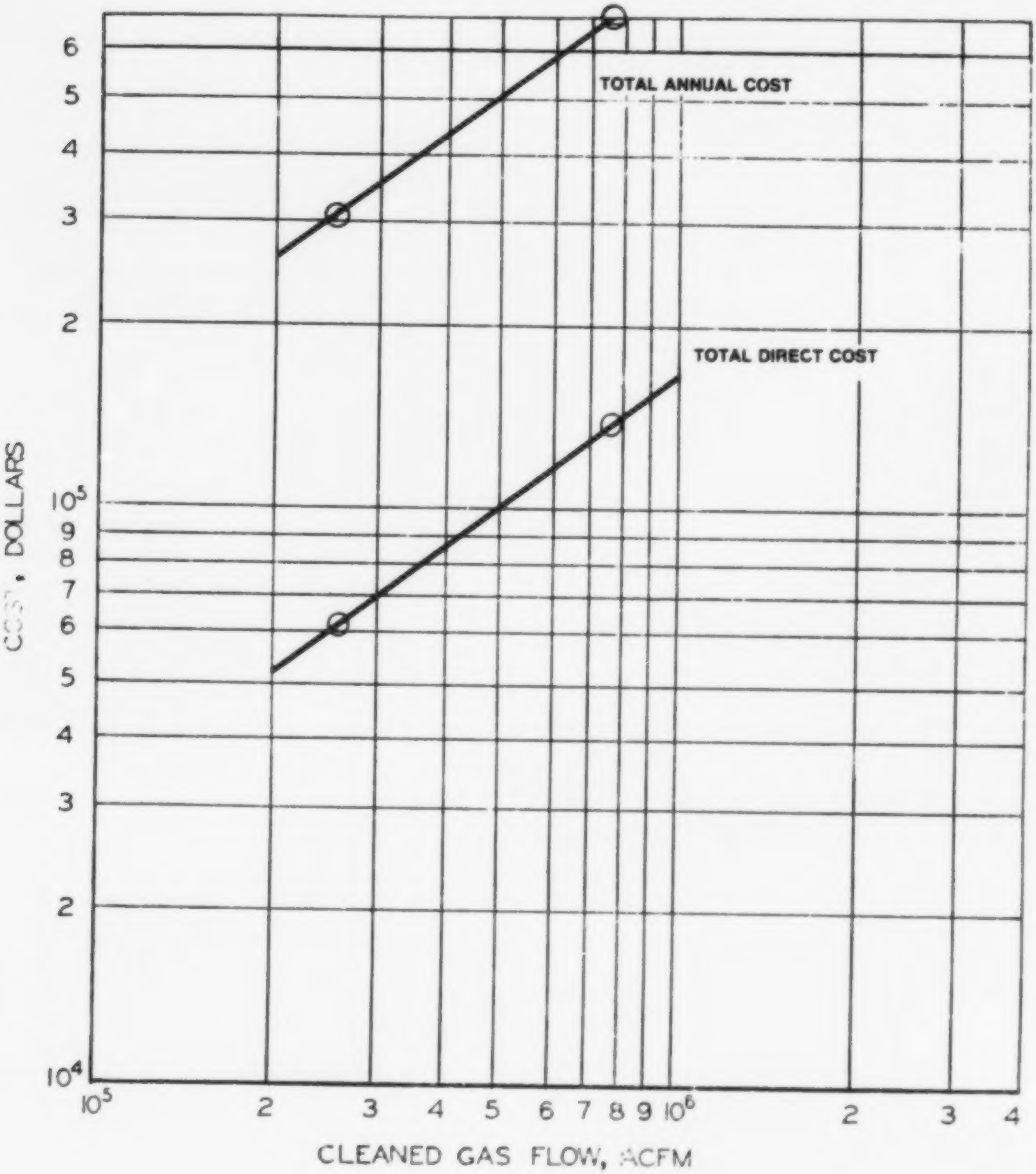


FIGURE 14

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE (HIGH EFFICIENCY)

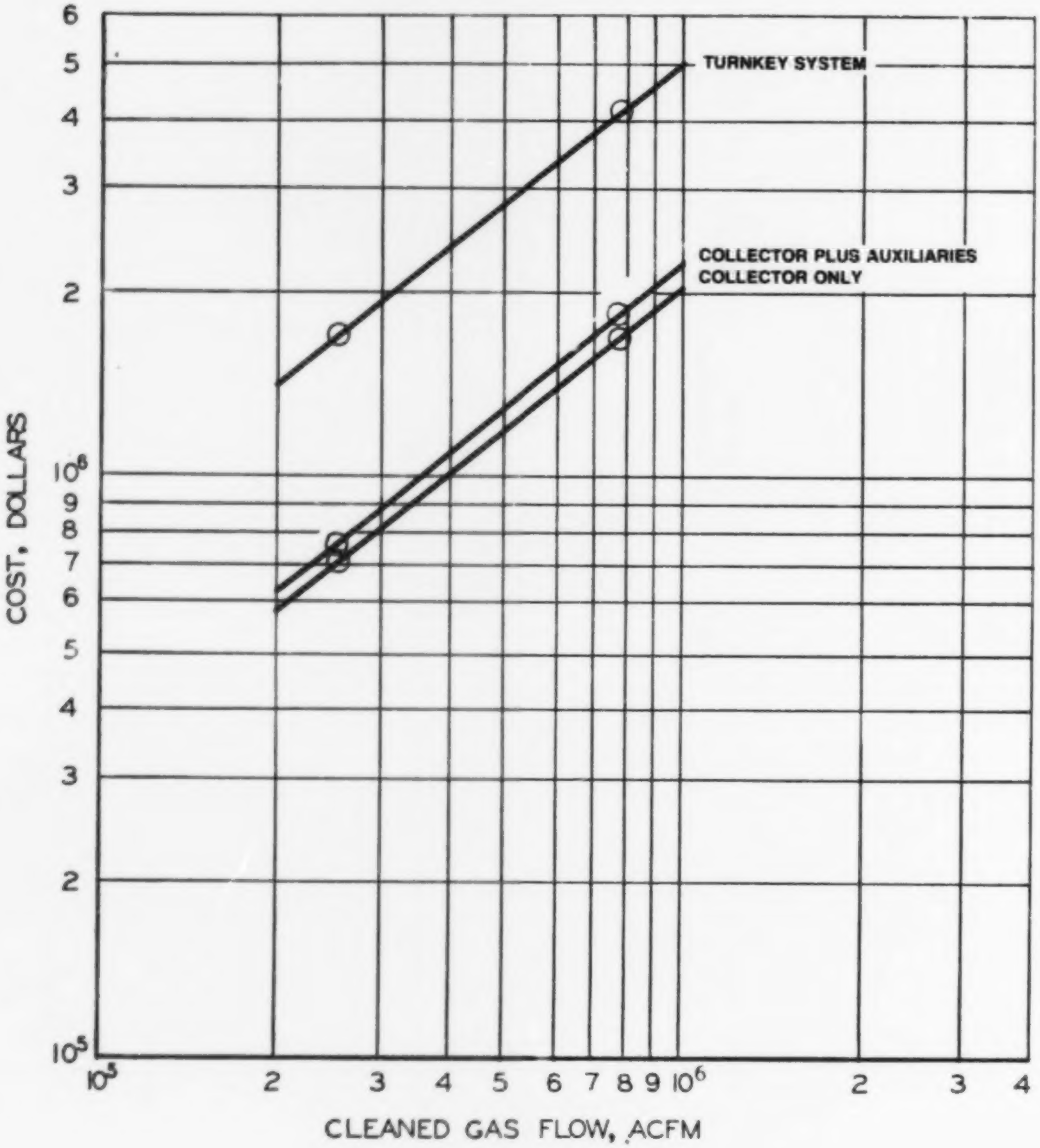
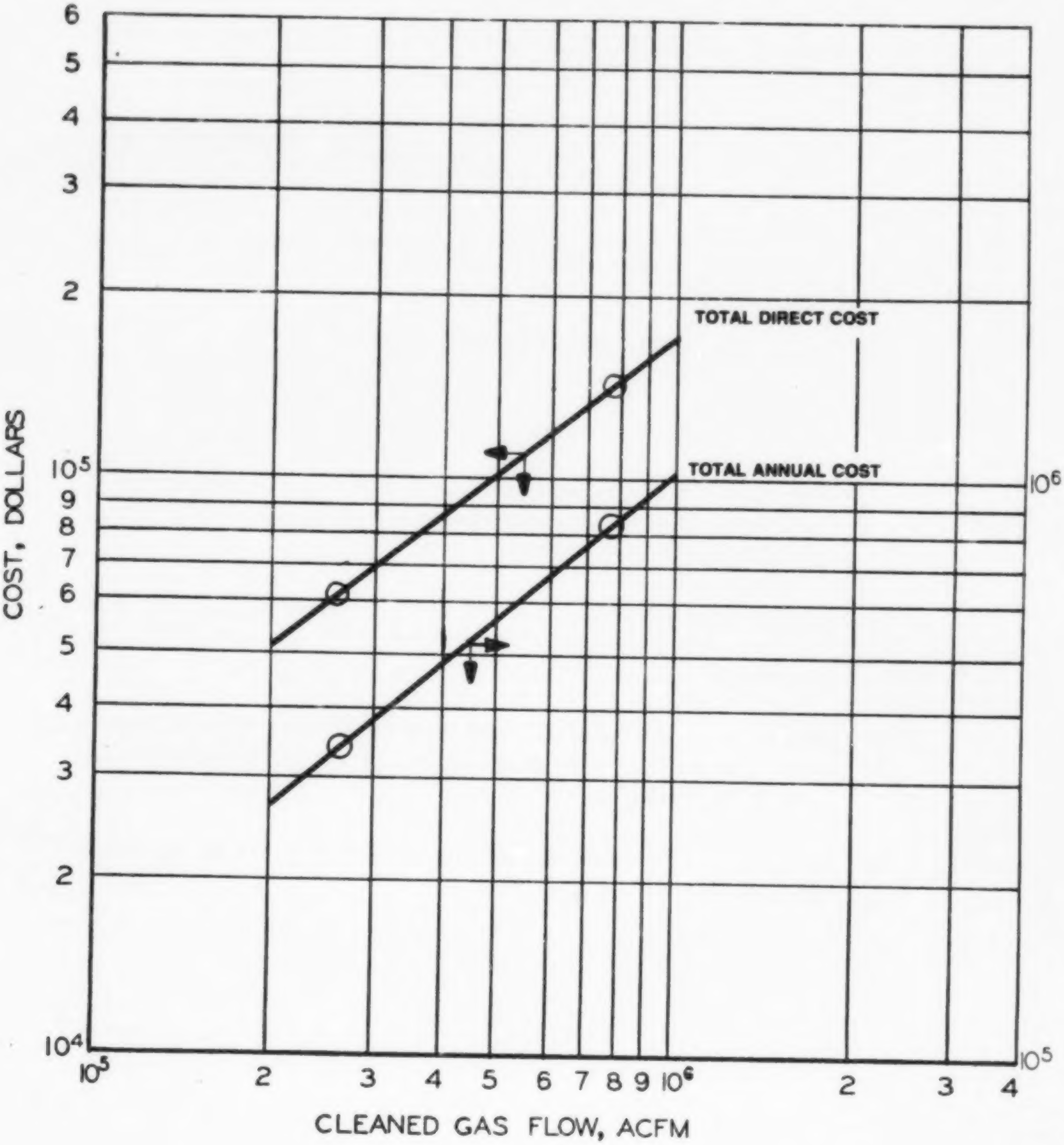


FIGURE 15

ANNUAL COST OF ELECTROSTATIC PRECIPITATORS FOR KRAFT PULP MILL CONTROLLED ODOR RECOVERY FURNACE (HIGH EFFICIENCY)



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2. FERROALLOY FURNACES

Ferroalloy is the term given to alloys of iron and non-ferrous metals such as silicon, chromium, and phosphorus. Ferroalloys are primarily used as alloying agents and deoxidants in the production of stainless steel, carbon steel and cast iron. In the United States, most ferroalloys are produced in either blast or electric furnaces. Blast furnaces have a lower operating cost but are limited to the production of ferroalloys with high carbon and low nonferrous metal content. Typical ferroalloys produced in blast furnaces are Spiegeleisen, ferromanganese, ferrosilicon, ferrochrome, and ferrophosphorus. Electric furnaces have higher operating costs but are required for the production of low carbon, high nonferrous metal content alloys. For example, ferrosilicon from a blast furnace is limited to 17% silicon. Its carbon content would be approximately 1.5%. Electric furnaces can produce ferrosilicon of over 85% silicon and less than 0.15% carbon. Typical ferroalloy compositions are listed in Table 13.

Since more than 80% of the domestic production of ferroalloys is performed in electric furnaces[1] the remainder of the narrative will deal with this type of furnace.

Most electric furnaces used in the ferroalloy industry are of the submerged arc type. They differ from the standard electric furnace used in steelmaking in that the majority of the electrical energy is used to promote a chemical reaction. There are generally three or six carbon electrodes. The electrodes are submerged into the melt half way between the hearth and the slag at the top. Figure 16 shows a typical submerged arc furnace. Energy requirements are high. Depending on the type of ferroalloy being produced, energy requirements[2] can vary from 1 to 6 kwh/lb. Furnace sizes range[3] from a few hundred to 50,000 kw.

Most ferroalloys such as ferromanganese, high carbon ferrochrome, and ferrosilicon are produced via a one-step process in a submerged arc electric furnace.[4, 5, 6] Other ferroalloys require further treatment after being tapped from the furnace. For example, molten high carbon ferrochrome is treated with oxygen to produce medium carbon ferrochrome.[6] Low carbon ferrochrome is produced via a multiple step process.[6] This process incorporates a slag furnace, an alloy furnace, a ladle, and two reaction vessels.

In the submerged arc electric furnace, raw materials are continuously fed into the top of the furnace. The raw materials consist of iron and nonferrous metal ores, reducing agents and fluxes. Typical reducing agents are coke, coal, coke fines, wood chips, and ferrosilicon alloys. At high temperatures, up to 2000°C, a reduction reaction occurs between the metal oxides and the reducing agents. The products of the reaction are molten alloy and carbon monoxide. The molten

TABLE 13

COMPOSITIONS OF TYPICAL FERROALLOYS

ALLOY TYPE	Wt.%								
	C	Mn	P	S	Si	V	Cr	Ti	Al
Ferromanganese (Std.)	7.5*	80	0.35*	0.05*	1.25*				
Ferromanganese (L.C.)	0.1-0.75	83	0.35	0.05	1.25				
Ferrosilicon	0.15*		0.05*	0.04*	50				
Ferrochromium (H.C.)	6				3*		73		
Ferrochromium (L.C.)	0.03-2.0				1.5*		73		
Ferrovanadium	3.5*		0.25*	0.40*	13*	35			1.5*
Silicomanganese		65			20				
Ferrotitanium	4				2.5			20	1.5
Spiegeleisen	6.5*	17	0.25*	0.05*	1.0-4.0				
Silvery Iron	1.5*		0.15*	0.06*	17				

*Maximum

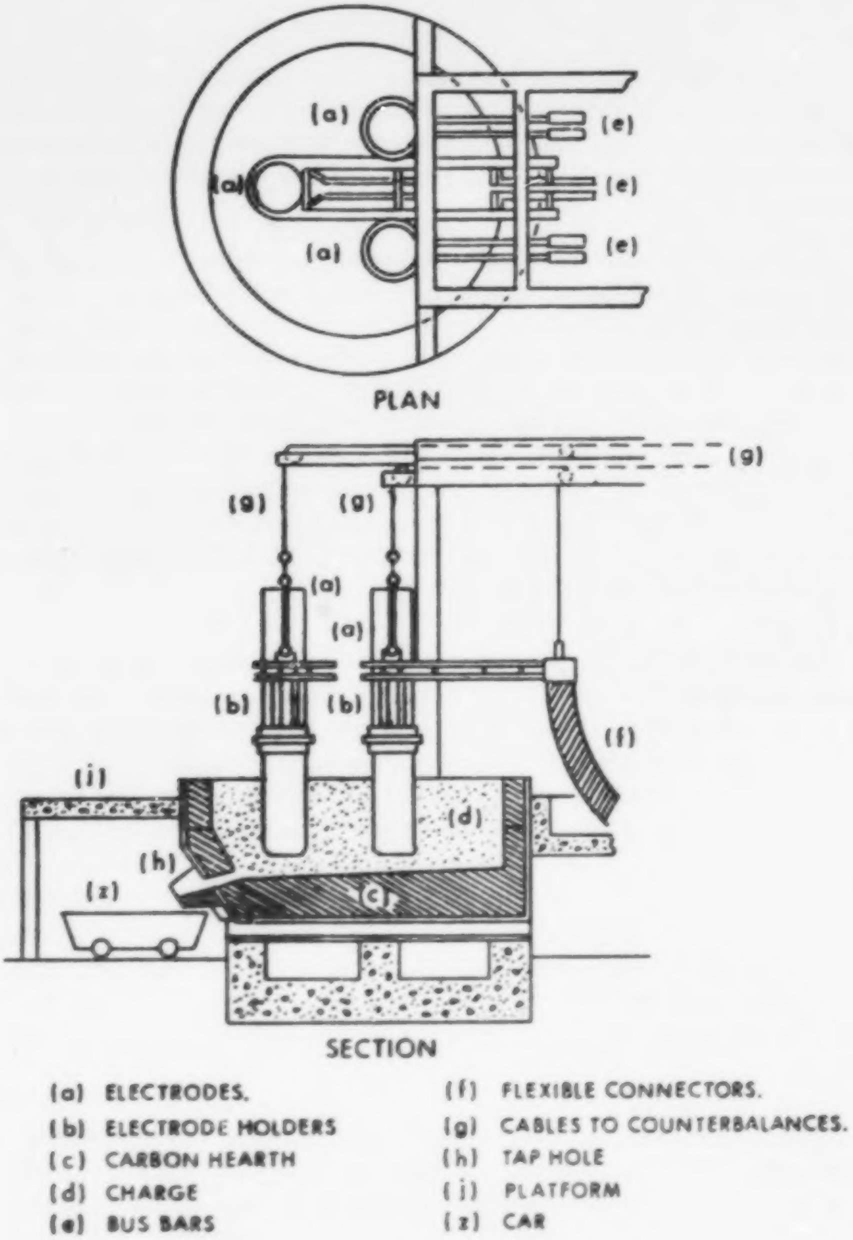
(a)
(a)
(a)
(e)
(e)
(e)
PLAN
(g)
(g)
(g)
(a)
(a)
(b)
(b)
(f)
(i)
(d)
(h)
(z)
(c)
SECTION
(a) ELECTRODES.
(b) ELECTRODE HOLDERS
(c) CARBON HEARTH
(d) CHARGE
(e) BUS BARS
(f) FLEXIBLE CONNECTORS.
(g) CABLES TO COUNTERBALANCES.
(h) TAP HOLE
(i) PLATFORM
(z) CAR

Figure 16. Electric furnace for ferroalloy production

alloy settles to the hearth. Here, it is tapped at one to five hour intervals. The carbon monoxide is the major gaseous emission from the melt. The basic overall reactions are listed in Table 14. The nonreduced constituents of the metal ores, known as slag, remain at the top of the melt. The slag is either discarded or is further processed.

Submerged arc furnaces can further be classified as open or closed according to the method of fume capture. Open hood furnaces allow the burning of carbon monoxide over the melt. This type of capture offers the advantage of easy access to the furnace for stoking and addition of raw material. Its chief disadvantage is the production of large volumes of gases. Closed hood furnaces collect only the fumes emitted directly from the melt. Their chief advantages are a low rate of gas flow into the subsequent pollution abatement equipment, and the potential for carbon monoxide recovery. The major disadvantages are the inaccessability of the furnace for stoking, the problems involved in creating a good seal, and the disposal of carbon monoxide from the abatement equipment. The numbers of closed and open hood furnaces in the U.S.A. are listed in Table 15[2].

Figures 17 and 18 show two types of closed hood furnaces. The completely sealed furnace has been used in Europe, Canada, and Japan.* Here, a mechanical seal is used around the electrode to prevent escape of gases. In this type of design all the off-gases are collected. There is no leakage into the room. The major problems are reliability of the mechanical seal and maintenance of sufficient mix height in the raw material additions ports (mix spouts) to preserve the seal.

The covered furnace is more common in the United States. Raw materials are fed around the electrodes thus creating the seal. This type of hood is reasonably simple. From 65% to 98% of the gaseous emissions are captured. The major disadvantage results from the gases which are not captured. Gases leak from around the electrodes and burn. The flames create further pollution and maintenance problems.

Control of emissions from open hood submerged arc electric ferroalloy furnaces[7] by fabric filters and wet scrubbers was dealt with under a prior EPA contract, No. 68-02-0301. In this narrative, additional cases of control of open hood emissions by fabric filters will be considered.

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*There is one such unit in the United States, as well.

TABLE 14

BASIC OVERALL REACTIONS FOR FERROALLOY PRODUCTION

Ore Constituents		Reducing Agents	Electrical Energy	Molten Alloy		Furnace Gas
Cr_2O_3	+	3C	→	2Cr	+	3CO
MnO	+	C	→	Mn		CO
SiO_2	+	2C	→	Si		2CO
Fe_2O_3	+	2C	→	2Fe		3CO
Al_2O_3						
CaO						
MgO_2				Slag		
SiO_2						

TABLE 15

DISTRIBUTION OF DOMESTIC FERROALLOY FURNACES

Furnace Type	Number in Use	% of Total
Submerged Arc - Open Hood	100-150	71-76
Submerged Arc - Closed Hood	30-35	21-18
Open Arc	12	8-6

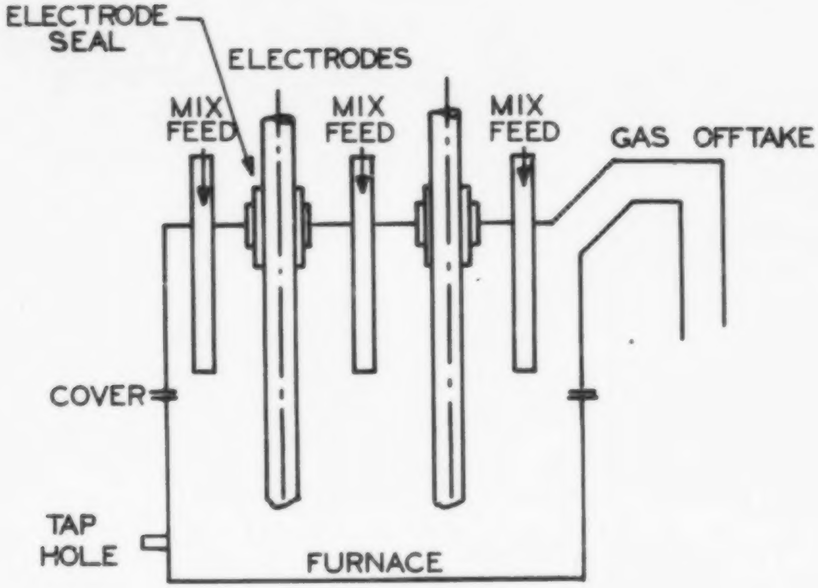

ELECTRODE SEAL
ELECTRODES
MIX FEED
MIX FEED
MIX FEED
GAS OFFTAKE
COVER
TAP HOLE
FURNACE

Figure 17. Sealed furnace for producing ferroalloys.

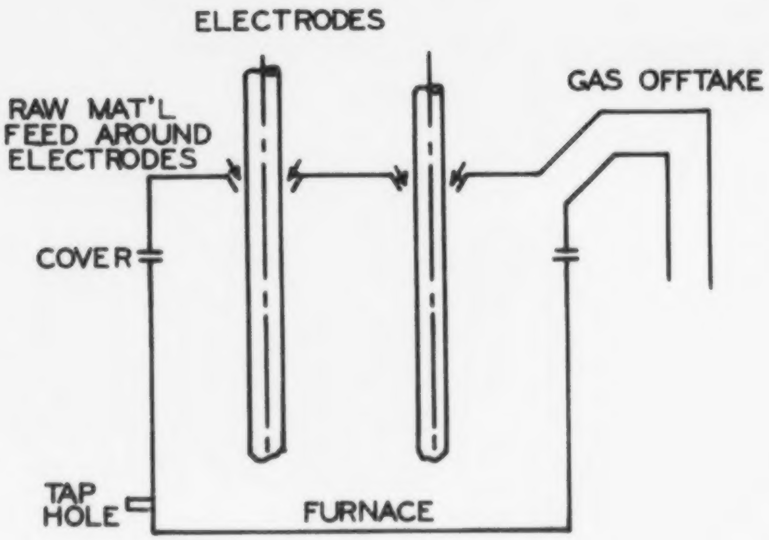

ELECTRODES
GAS OFFTAKE
RAW MAT'L FEED AROUND ELECTRODES
COVER
TAP HOLE
FURNACE

Figure 18. Covered furnace for producing ferroalloys.

NATURE OF THE GASEOUS DISCHARGE

Carbon monoxide is the major by-product of ferroalloy production. The weight of CO emitted from the melt can exceed the weight of alloy produced. For example, Table 16 shows a weight balance for production of 45% ferrosilicon. The amount of carbon monoxide emitted is 2.12 tons for every 2 tons of ferroalloy produced[8].

The amount of gaseous emissions from closed and open furnaces is quite different. The volume can be as much as 50 times greater with the open hood. For example, Table 17 shows a comparison of open and closed furnaces for the production of 50% ferrosilicon. In this example, the difference in gas flow rate was a factor of 26.

Only two and one-half volumes of air are needed to convert one volume of carbon monoxide to carbon dioxide. The remainder of the excess air used with the open hood design is required for adequate ventilation around the hood to prevent leakage of fumes into the room.

Other components of the gaseous discharge include hydrogen and volatile hydrocarbon. The volatile hydrocarbon comes from the electrodes and from oil on the surface of the steel shavings.

NATURE OF THE PARTICULATE EMISSIONS

Operation of ferroalloy furnaces produces particulate emissions at three principal points:

1. The top of the furnace, carried out with the reaction gases.
2. The furnace tapholes. Since most furnaces are tapped cyclically rather than continuously, the source is active only about 15% of the time.
3. The ladle after tapping, which is also a non-continuous source of particulates.

The particulates emitted are small in size and are composed of the oxides of the metals being produced and used in the process. Examples are given in Table 18. Attention should be drawn to the submicron size of the particles. Particles of this size are difficult to collect and usually require high expenditures of energy. Agglomeration of the particles can make the effective particle size to the collector much larger than that indicated in the Table. Grain loadings have been reported in the range of 5 to 30 gr/SCF for the closed hood system and 0.1 to 2 gr/SCF for the open hood system[9].

TABLE 16

WEIGHT BALANCE FOR PRODUCTION OF 45% FERROSILICON

Production Rate Basis: 2 Ton/Hr of Alloy

Input, ton/hr		Output, ton/hr*	
Quartzite	2.02	Ferrosilicon	2.00
Coke	1.18	Slag	0.06
Steel Shavings	1.15	Gas	2.33
Electrode Mass	0.04		
	4.39		4.39

*Averaged over operating cycle

TABLE 17

COMPARISON OF GAS FLOWS FROM OPEN AND CLOSED HOOD 50 MW SUBMERGED ARC FURNACES MAKING 50% FERROSILICON

	Closed Hood	Open Hood
Flow, ACFM	20,000	310,000
Temperature, °F	1,100	460
Flow, SCFM	6,600	175,000

TABLE 18

PROPERTIES OF PARTICULATE EMISSIONS FROM FERROALLOY FURNACES

Alloy Type	50% Fe Si	Si Mn	Fe Mn	H.C. Fe Cr
Furnace Hood Type	Open	Covered	Open	Covered
Particle Size, μ				
Maximum	0.75	0.75	0.75	1.0
Range of Most Particles	0.05-0.3	0.2-0.4	0.05-0.4	0.1-0.4
Chemical Analysis, Wt. %*				
SiO_2	63-88	15.63	25.48	20.96
FeO		6.75	5.96	10.92
MgO		1.12	1.03	15.41
CaO			2.24	
MnO		31.35	33.60	2.84
Al_2O_3		5.55		7.12
Cr_2O_3				29.27
LOI**		23.25	8.38	

*Standard metal oxides analysis — compounds not necessarily found in the chemical forms listed.

**Loss in weight on ignition.

POLLUTION CONTROL CONSIDERATIONS

As previously mentioned, the size of the particles emitted from a ferroalloy furnace is very small. There are five types of pollution control equipment which could be employed to control this emission. They are:

1. Dynamic scrubber
2. Venturi scrubber
3. Ceramic tube filter
4. Electrostatic precipitator
5. Fabric filter

The dynamic scrubber has been successfully employed to collect particulate matter from ferroalloy furnaces. Collection efficiencies of greater than 98% for particulates and 79% for organics have been reported.[9] The major problems are a design capacity limitation of 4000 ACFM (2000 ACFM is standard size sold) per unit, high power usage, high clean water consumption, and disposal of the liquid discharge.

The venturi scrubber has also been used to clean gaseous emissions from ferroalloy furnaces. Collection efficiencies of greater than 98% have been reported with open hood furnaces.[9] High pressure drops are required for successful operation. However, power and water consumption are less than with the dynamic scrubber.

Ceramic tube filters have been used in Germany on calcium carbide electric furnaces. This filter operates at 600°C which is above the combustion temperature of the hydrocarbons in the gas stream. The capital cost is high.

Electrostatic precipitators have not been widely used to control ferroalloy furnace emissions in this country although they have been used to some extent in Europe. The principal problems are poor resistivity and high capital cost.

Fabric filters are widely used as control devices for emissions from open hood ferroalloy furnaces. High collection efficiencies are obtainable but the unit must be installed so as to avoid the operating problems which are inherent in the application of fabric filters to furnace gases. Furnace gases must be cooled prior to entering the fabric filter in order to avoid damaging the bags which have low design limit temperatures. Provision must be made to minimize the condensation of hydrocarbon on the bags which could lead to blinding. Provision must also be made to capture sparks and burning particles before they can enter the fabric filter and burn holes in the bags.

SPECIFICATIONS AND COSTS

Abatement specifications for fabric filters were written for both small and large sized operations for three types of ferroalloy furnace installations: ferrosilicon furnaces with air dilution coolers, silicon metal furnaces with air dilution coolers, and silicon metal furnaces with evaporative coolers.

Estimates of capital costs and annual operating costs made by the bidders for each system were averaged and presented in the cost tables and graphs. Reverse air or shaker type collectors with an average air to cloth ratio of about 2:1 were used in each of the cases. One of the three bidders specified a $CaCO_3$ pre-coat required for all three systems and showed the pre-coat cost in his annual operating cost estimate. This fact is footnoted on the operating cost tables but is not included in the averaged cost data presented.

Specifications for fabric filter systems for ferroalloy furnaces are shown in Tables 19 and 20. Cost data are presented in Tables 21 and 22 and Figures 19 and 20. This system uses an air dilution cooler preceding the fabric filter.

The specifications for fabric filter systems for silicon metal furnaces using air dilution coolers are shown in Tables 23 and 24. Cost data are presented in Tables 25 and 26 and Figures 21 and 22.

The specifications for fabric filter systems for silicon metal furnaces using evaporative coolers are shown in Tables 27 and 28. Cost data are presented in Tables 29 and 30 and Figures 23 and 24.

The same sized silicon metal furnaces were specified for both the air dilution and evaporative cooled systems. This allows a comparison of the differences in costs of the two alternative cooling methods.

TABLE 19

FABRIC FILTER PROCESS DESCRIPTION FOR FERROSILICON FURNACE SPECIFICATION

A fabric filter is to remove particulates from the effluent fume from a new ferrosilicon furnace installation. The fabric filter is to be preceded by an air dilution cooler. The furnace is of the submerged arc type. It is charged with raw material continuously and is tapped intermittently on a two-hour cycle. The furnace is located inside the building and the air pollution control system is located on the outside. The ductwork from the furnace hood to the beginning of the air pollution control system is 200 ft. long and consists of 100 ft. of vertical and 100 ft. of horizontal duct.

The abatement system shall include the following:

1. *Hoods for the capture of gaseous and particulate contaminants from the tap hole and ladle. The capture hood for the top of the furnace will be supplied by others.*
2. *All of the ductwork, connecting hoods, and abatement equipment.*
3. *Fans sized with at least 20% excess capacity on volume and 10% excess capacity on static pressure. The location of the fans shall be on the inlet side of the abatement system.*
4. *A mechanical collector upstream of the fabric filter and fan to help protect the bags from large burning particles.*
5. *Compartmented design of the fabric filter to permit shutdown of each section for maintenance.*
6. *Sufficient capacity for operation with one compartment out of service for cleaning.*
7. *Bags with a temperature rating of ≤500°F.*
8. *A high temperature by-pass around the fabric filter for use during operational upsets.*
9. *Dust hoppers and conveyors.*
10. *Dust storage bins with 24-hour capacity.*

TABLE 20

FABRIC FILTER OPERATING CONDITIONS FOR FERROSILICON FURNACE SPECIFICATION

Alloy Type	75% FeSi	75% FeSi
Furnace Type	Open	Open
Furnace Size, mw	25	40
Product Rate, ton/hr	2.84	4.55
Process Weight, ton/hr	12.78	20.48
Gas to Collector		
ACFM[1]	750,500	1,200,800
Temperature, °F	400	400
SCFM	462,500	740,000
Moisture Content, vol%	2.0	2.0
Solids Loading		
gr/ACF	0.40	0.40
lb/hr	2,600	4,160
Gas from Collector		
ACFM	750,500	1,200,800
Temperature, °F	400	400
SCFM	462,500	740,000
Moisture Content, vol%	2.0	2.0
Solids Loading		
gr/ACF	0.01	0.01
lb/hr	64	103
Collection Efficiency,%	97.5[2]	97.5[2]

[1] Includes 60,000 ACFM @ 150°F from taphole hood.

[2] Performance will exceed stated efficiency. The stated efficiency represents an outlet loading of 0.01 gr/ACF for guarantee purposes.

TABLE 21

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR FABRIC FILTERS FOR FERROSILICON FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			750,500	1,200,800
°F			400	400
SCFM			462,500	740,000
Moisture Content, Vol. %			2.0	2.0
Effluent Contaminant Loading				
gr/ACF			.40	.40
lb/hr			2,600	4,160
Cleaned Gas Flow				
ACFM			750,500	1,200,800
°F			400	400
SCFM			462,500	740,000
Moisture Content, Vol. %			2.0	2.0
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			64	103
Cleaning Efficiency, %			97.5	97.5
(1) Gas Cleaning Device Cost			1,258,833	1,957,350
(2) Auxiliaries Cost			409,567	624,647
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			1,226,433	1,901,700
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			2,894,833	4,483,697

FIGURE 19

CAPITAL COST OF FABRIC FILTERS FOR FERROSILICON FURNACES

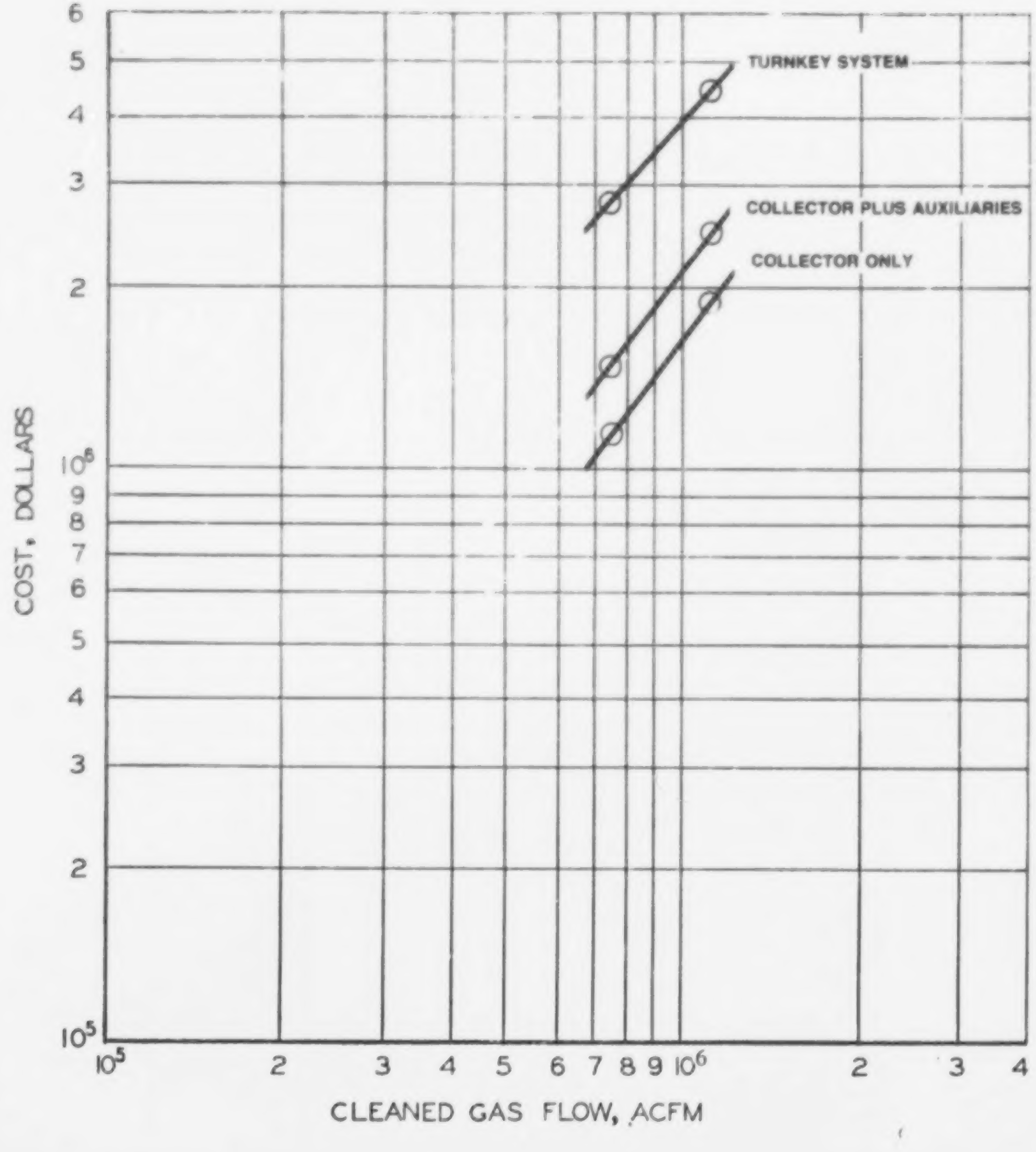


TABLE 22

ANNUAL OPERATING COST DATA (COST IN $/YEAR) FOR FABRIC FILTERS FOR FERROSILICON FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year-8600					
Operating Labor (if any)					
Operator	$6/mh			11,874	13,188
Supervisor	$8/mh			520	648
Total Operating Labor				12,394	13,836
Maintenance					
Labor	$6/mh			9,438	13,656
Materials				2,167	3,250
Total Maintenance				11,605	16,906
Replacement Parts				89,560	143,361
Total Replacement Parts				89,560	143,361
Utilities					
Electric Power	$0.011/kwh			208,700	334,400
Fuel					
Water (Process)	$0.25			875	1,190
Water (Cooling)					
Chemicals, Specify *					
Total Utilities				209,575	335,590
Total Direct Cost				323,134	509,693
Annualized Capital Charges	16% of Cap			463,173	717,392
Total Annual Cost				786,307	1,227,085

* One bidder recommended the use of a $CaCO_3$ precoat at a cost of $20/ton.

FIGURE 20

ANNUAL COST OF FABRIC FILTERS FOR FERROSILICON FURNACE

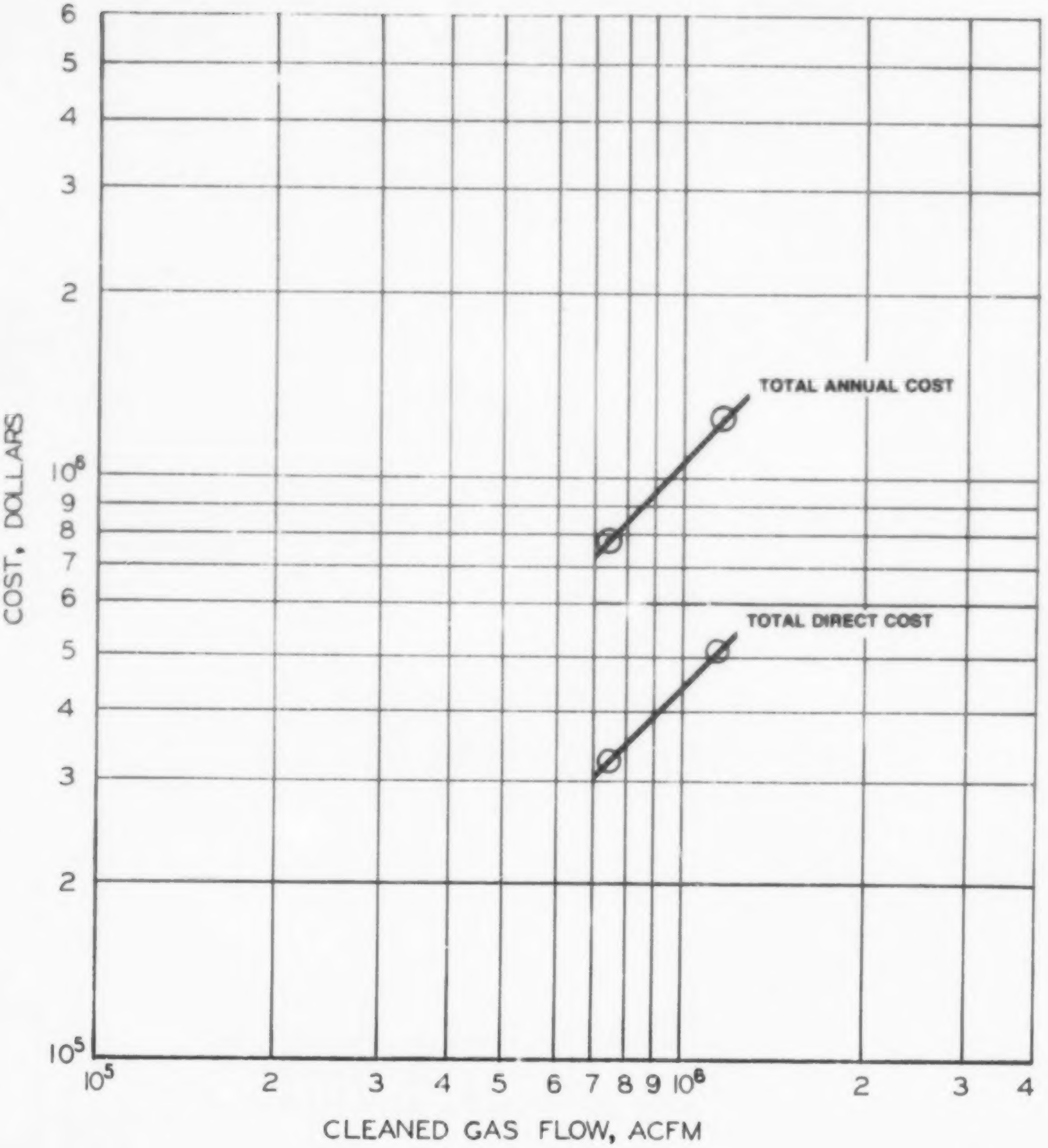


TABLE 23

FABRIC FILTER PROCESS DESCRIPTION FOR SILICON METAL FURNACE SPECIFICATION

A fabric filter is to remove particulates from the effluent fume from a new silicon metal furnace installation. The fabric filter is to be preceded by an air dilution cooler. The furnace is of the submerged arc type. It is charged with raw material continuously and is tapped intermittently on a two-hour cycle. The furnace is located inside the building and the air pollution control system is located on the outside. The ductwork from the furnace hood to the beginning of the air pollution control system is 200 ft. long and consists of 100 ft. of vertical and 100 ft. of horizontal duct.

The abatement system shall include the following:

1. *Hoods for the capture of gaseous and particulate contaminants from the tap hole and ladle. The capture hood for the top of the furnace will be supplied by others.*
2. *All of the ductwork, connecting hoods, and abatement equipment.*
3. *Fans sized with at least 20% excess capacity on volume and 10% excess capacity on static pressure. The location of the fans shall be on the inlet side of the abatement system.*
4. *A mechanical collector upstream of the fabric filter and fan to help protect the bags from large burning particles.*
5. *Compartmented design of the fabric filter to permit shutdown of each section for maintenance.*
6. *Sufficient capacity for operation with one compartment out of service for cleaning.*
7. *Bags with a temperature rating of ≈500°F.*
8. *A high temperature by-pass around the fabric filter for use during operational upsets.*
9. *Dust hoppers and conveyors.*
10. *Dust storage bins with 24-hour capacity.*

TABLE 24

FABRIC FILTER OPERATING CONDITIONS FOR SILICON METAL FURNACE SPECIFICATION

Alloy Type	*Silicon*	*Silicon*
Furnace Type	*Open*	*Open*
Furnace Size, mw	*15*	*25*
Product Rate, ton/hr	*1.07*	*1.79*
Process Weight, ton/hr	*5.24*	*8.77*
Gas to Collector		
ACFM[1]	*450,300*	*750,500*
Temperature, °F	*400*	*400*
SCFM	*277,500*	*462,500*
Moisture Content, vol%	*2.0*	*2.0*
Solids Loading		
gr/ACF	*0.56*	*0.56*
lb/hr	*2,160*	*3,600*
Gas from Collector		
ACFM	*450,300*	*750,500*
Temperature, °F	*400*	*400*
SCFM	*277,500*	*462,500*
Moisture Content, vol%	*2.0*	*2.0*
Solids Loading		
gr/ACF	*0.01*	*0.01*
lb/hr	*39*	*64*
Collection Efficiency, %	*98.2*[2]	*98.2*[2]

[1] *Includes 60,000 ACFM @ 150°F from taphole hood.*

[2] *Performance will exceed stated efficiency. The stated efficiency represents an outlet loading of 0.01 gr/ACF for guarantee purposes.*

TABLE 25

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR FABRIC FILTERS FOR SILICON METAL FURNACE (DILUTION COOLING)

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			450,000	750,500
°F			400	400
SCFM			277,500	462,500
Moisture Content, Vol. %			2.0	2.0
Effluent Contaminant Loading				
gr/ACF			.56	.56
lb/hr			2,160	3.600
Cleaned Gas Flow				
ACFM			450,000	750,500
°F			400	400
SCFM			277,500	464,500
Moisture Content, Vol. %			2.0	2.0
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			39	64
Cleaning Efficiency, %			98.2	98.2
(1) Gas Cleaning Device Cost			765,100	1,258,633
(2) Auxiliaries Cost			263,733	415,200
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			768,873	1,231,800
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			1,797,706	2,905,633

FIGURE 21

CAPITAL COST OF FABRIC FILTERS FOR SILICON METAL FURNACE (DILUTION COOLING)

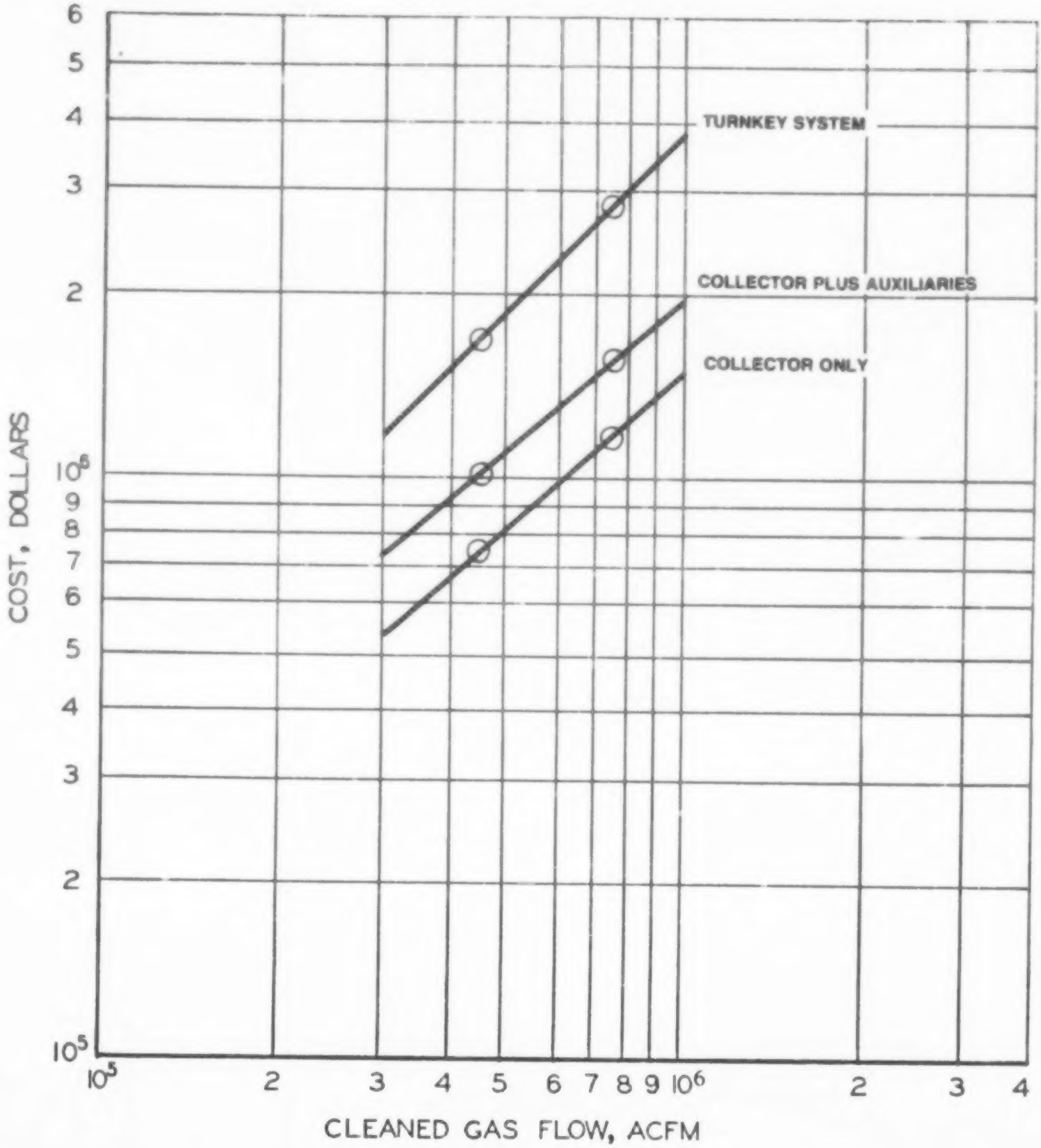


TABLE 26

ANNUAL OPERATING COST DATA (COST IN $/YEAR) FOR FABRIC FILTERS FOR SILICON METAL FURNACE (DILUTION COOLING)

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year -8600					
Operating Labor (if any)					
Operator	$6/mh			7,068	11,874
Supervisor	$8/mh			312	520
Total Operating Labor				7,380	12,394
Maintenance					
Labor	$6/mh			6,408	9,486
Materials				1,383	2,167
Total Maintenance				7,791	11,653
Replacement Parts				54,363	87,947
Total Replacement Parts				54,363	87,947
Utilities					
Electric Power	$0.011/kwh			114,100	215,800
Fuel					
Water (Process)	$0.25 M/gal			728	875
Water (Cooling)					
Chemicals, Specify*					
Total Utilities				114,828	215,675
Total Direct Cost				184,362	325,669
Annualized Capital Charges	16% of Cap			287,633	464,901
Total Annual Cost				471,995	790,570

*One bidder recommended the use of a $CaCO_3$ precoat at a cost of $20/ton.

FIGURE 22

ANNUAL COST OF FABRIC FILTERS FOR SILICON METAL FURNACE (DILUTION COOLING)

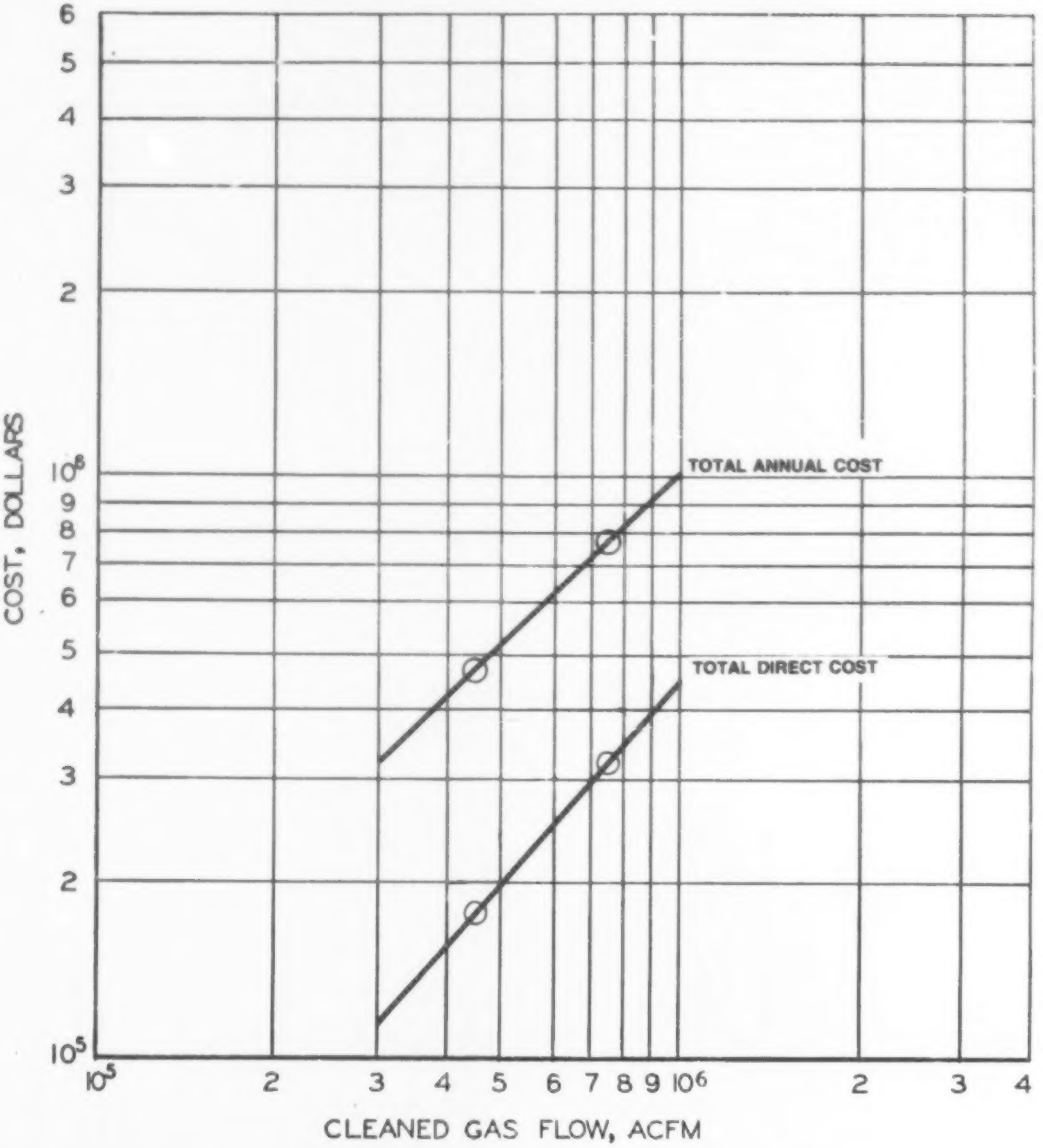


TABLE 27

FABRIC FILTER PROCESS DESCRIPTION FOR SILICON METAL FURNACE SPECIFICATION

A fabric filter is to remove particulates from the effluent fume from a new silicon metal furnace installation. The fabric filter is to be preceded by an evaporative cooler. The furnace is of the submerged arc type. It is charged with raw material continuously and is tapped intermittently on a two-hour cycle. The furnace is located inside the building and the air pollution control system is located on the outside. The ductwork from the furnace hood to the beginning of the air pollution control system is 200 ft. long and consists of 100 ft. of vertical and 100 ft. of horizontal duct.

The abatement system shall include the following:

1. *Hoods for the capture of gaseous and particulate contaminants from the tap hole and ladle. The capture hood for the top of the furnace will be supplied by others.*
2. *All of the ductwork, connecting hoods, and abatement equipment.*
3. *Fans sized with at least 20% excess capacity on volume and 10% excess capacity on static pressure. The location of the fans shall be on the inlet side of the abatement system.*
4. *A mechanical collector upstream of the fabric filter and fan to help protect the bags from large burning particles.*
5. *An evaporative cooler to lower the temperature of the inlet gas to 400°F.*
6. *Compartmented design of the fabric filter to permit shutdown of each section for maintenance.*
7. *Sufficient capacity for operation with one compartment out of service for cleaning.*
8. *Bags with a temperature rating of <500°F.*
9. *A high temperature by-pass around the fabric filter for use during operational upsets.*
10. *Dust hoppers and conveyors.*
11. *Dust storage bins with 24-hour capacity.*

TABLE 28

FABRIC FILTER OPERATING CONDITIONS FOR SILICON METAL FURNACE SPECIFICATION

Alloy Type	Silicon	Silicon
Furnace Type	Open	Open
Furnace Size, mw	15	25
Product Rate, ton/hr	1.07	1.79
Process Weight, ton/hr	5.24	8.77
Gas to Gas Cooler		
ACFM[1]	261,700	436,200
Temperature, °F	1,100	1,100
Moisture Content, vol%	2.0	2.0
Gas to Collector		
ACFM[1]	176,900	294,900
Temperature, °F	400	400
SCFM	109,000	181,700
Moisture Content, vol%	18.5	18.5
Solids Loading		
gr/ACF	1.42	1.42
lb/hr	2,160	3,600
Gas from Collector		
ACFM	176,900	294,900
Temperature, °F	400	400
SCFM	109,000	181,700
Moisture Content, vol%	18.5	18.5
Solids Loading		
gr/ACF	0.01	0.01
lb/hr	15	25
Collection Efficiency, %	99.3[2]	99.3[2]

[1] Includes 60,000 ACFM @ 150°F from taphole hood.

[2] Performance will exceed stated efficiency. The stated efficiency represents an outlet loading of 0.01 gr/ACF for guarantee purposes.

TABLE 29

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR FABRIC FILTERS FOR SILICON METAL FURNACE (EVAPORATIVE COOLING)

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			261,700	436,200
°F			1,100	1,100
SCFM			88,900	148,200
Moisture Content, Vol. %			2.0	2.0
Effluent Contaminant Loading				
gr/ACF			.96	.96
lb/hr			2,160	3,600
Cleaned Gas Flow				
ACFM			176,900	294,900
°F			400	400
SCFM			109,000	181,700
Moisture Content, Vol. %			18.5	18.5
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			15	25
Cleaning Efficiency, %			99.3	99.3
(1) Gas Cleaning Device Cost			326,802	528,163
(2) Auxiliaries Cost			203,399	306,217
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			394,023	605,170
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			924,224	1,439,550

FIGURE 23

CAPITAL COST OF FABRIC FILTERS FOR SILICON METAL FURNACE (EVAPORATIVE COOLING)

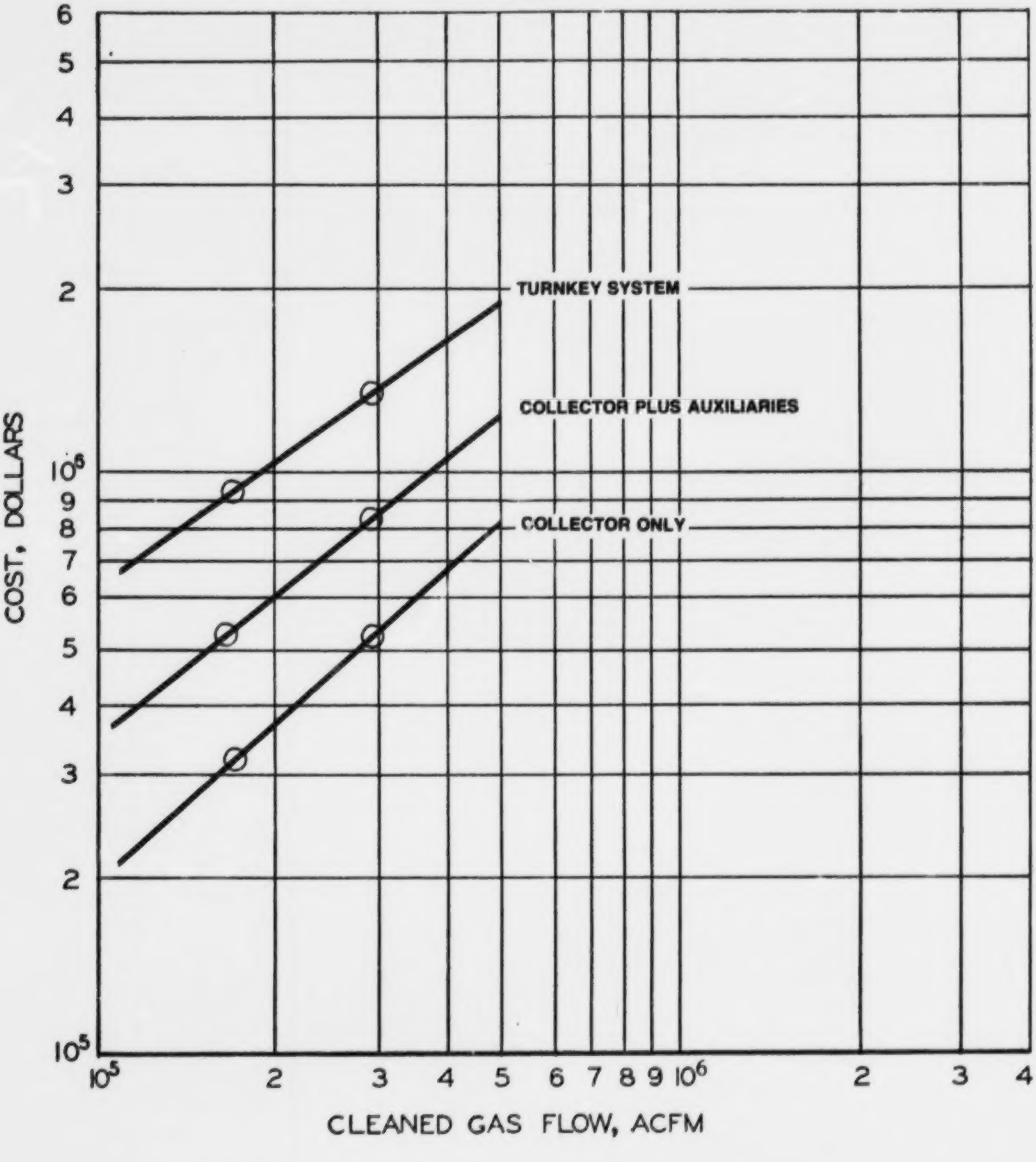


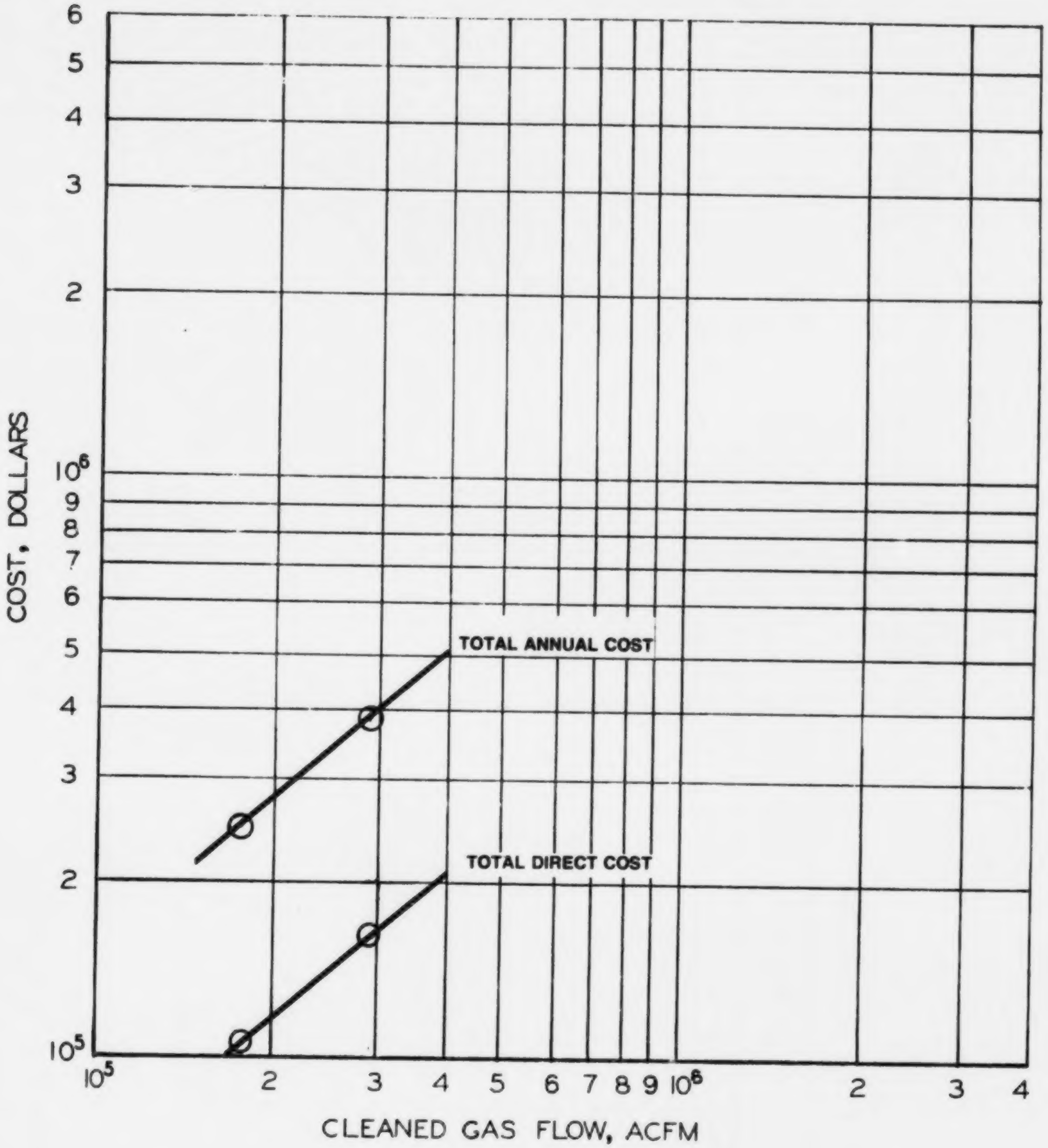
TABLE 30

ANNUAL OPERATING COST DATA (COST IN $/YEAR) FOR FABRIC FILTERS FOR SILICON METAL FURNACE (EVAPORATIVE COOLING)

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year - 8600					
Operating Labor (if any)					
Operator	$6/mh			5,580	6,606
Supervisor	$8/mh			307	332
Total Operating Labor				5,887	6,938
Maintenance					
Labor	$6/mh			4,743	6,846
Materials				1,198	1,857
Total Maintenance				5,941	8,703
Replacement Parts				26,281	40,370
Total Replacement Parts				26,281	40,370
Utilities					
Electric Power	$0.011/kwh			60,600	100,400
Fuel					
Water (Process)	$0.25 M/gal			417	583
Water (Cooling)	$0.05 M/gal			1,457	2,209
Chemicals, Specify					
Total Utilities				68,302	112,030
Total Direct Cost				106,411	168,041
Annualized Capital Charges	16% of Cap			147,876	230,328
Total Annual Cost				254,287	398,369

FIGURE 24

ANNUAL COST OF FABRIC FILTERS
FOR SILICON METAL FURNACES
(EVAPORATIVE COOLING)



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3. GRAIN CLEANING HOUSES

For centuries, grain has been an important food source for both man and animals. This importance is still apparent today, with world-wide annual grain production now in excess of 1.3 billion metric tons, nearly 300 million metric tons of which are grown in North America. Table 31 shows a breakdown of this production by grain type.[1] Two factors which account for the wide use of grain as a food source are ease of growing, and storage stability.

Milling of grain into flour and other products is an important industry throughout the world. Originally, milling was done in the home. Millstones were highly valued household articles, being passed on from generation to generation. Gradually, custom milling came into existence, and it has developed into the large complex grain milling industry of today.

The milling process involves many steps, of which the following are among the more important. Grain is received at the mill, given a cursory cleaning to remove large objects such as sticks, rocks, pieces of metal, and cloth, and is then sent to storage. As needed, it is withdrawn, and given a much more thorough cleaning, including removing small stones, sticks, bits of metal, foreign seeds, chaff, and dirt. The grain is then "tempered" by the addition of the right amount of moisture to enhance milling properties. Sometimes, heat is also added, in which case the process is called "conditioning". The grain is then ground into finished product and conveyed to storage where it awaits distribution.

Because the quality of the finished product is dependent largely upon the cleanliness of the grain, grain cleaning is an important step in the milling process. However, the cleaning of grain generates by-products which could result in environmental problems. This report will focus on the grain cleaning process and will include a discussion of the process, by-products, pollution control equipment, and related capital and operating costs.

PROCESS DESCRIPTION

Figure 25 shows a typical layout configuration for a grain cleaning house[2]. Grain is withdrawn from a storage bin as needed, usually on a continuous basis, and conveyed to the grain cleaning house. Several methods of conveyance are used, with screw, belt, bucket, and pneumatic conveyors being the most popular. These methods are used throughout the mill. The grain is weighed and sent to a separation device, such as an oscillating inclined sieve which is called a scalper. Here, dirt, dust, small pebbles and sticks, and other small objects are separated from the grain. During scalping, the grain passes over sets of air jets, called

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TABLE 31

ANNUAL GRAIN PRODUCTION STATISTICS[1]

REGION	WORLD			NORTH AMERICA		
Year	1969	1970	1971	1969	1970	1971
All Cereals, mmt(*)	1195.6	1203.5	1305.7	239.8	215.4	275.6
Wheat, mmt	315.6	316.7	340.2	58.4	46.5	58.5
Rice, mmt	294.9	305.8	508.9	4.1	3.8	3.8
Maize, mmt	264.8	259.7	307.9	118.3	107.0	143.6
Barley, mmt	137.1	138.5	152.1	17.5	18.0	24.5

*Millions of metric tons

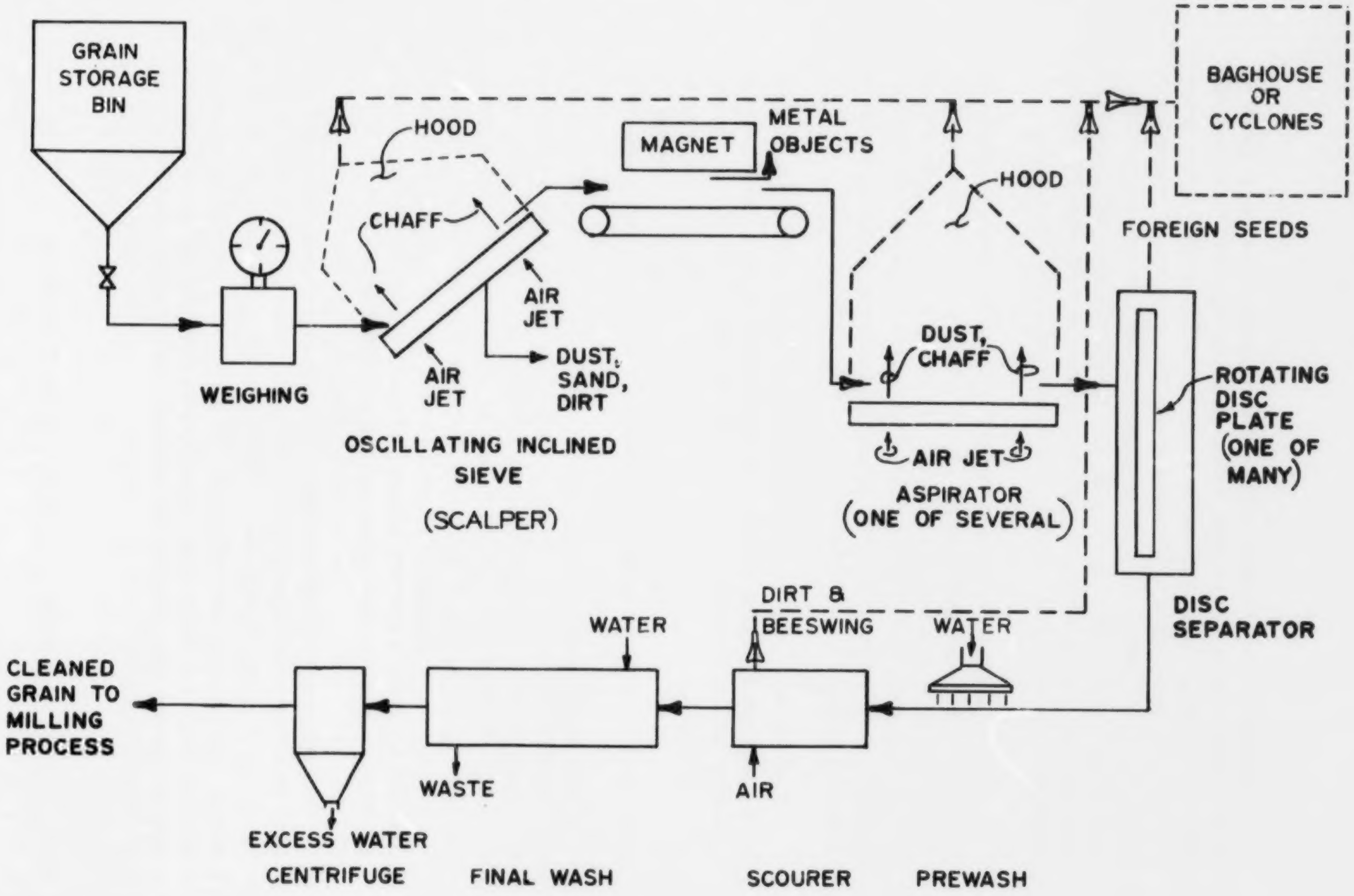

GRAIN STORAGE BIN
WEIGHING
HOOD
CHAFF
AIR JET
AIR JET
DUST, SAND, DIRT
OSCILLATING INCLINED SIEVE
(SCALPER)
MAGNET
METAL OBJECTS
HOOD
DUST, CHAFF
AIR JET
ASPIRATOR (ONE OF SEVERAL)
BAGHOUSE OR CYCLONES
FOREIGN SEEDS
ROTATING DISC PLATE (ONE OF MANY)
DISC SEPARATOR
DIRT & BEESWING
WATER
WATER
AIR
WASTE
EXCESS WATER
CLEANED GRAIN TO MILLING PROCESS
CENTRIFUGE
FINAL WASH
SCOURER
PREWASH

Figure 25. Flow diagram for Grain Cleaning House

aspirators, located in the scalper. These aspirators dislodge very light objects of large surface area, i.e., wheat chaff, without disturbing the grain. These scalpers are similar to those used at grain elevators and terminals where the grain is first brought by farmers, but have a smaller screen size. Scalpers at elevators and terminals are used solely for removal of large objects from the grain such as rocks, large sticks, pieces of iron, rags, and so on. This process could be classified as grain cleaning, but will not be the principal process studied here. Instead, this report will focus on the grain cleaning process used just prior to grain milling.

Next, ferrous metal pieces still remaining in the grain are removed by magnets. This metal could cause serious damage to mill rolls if it were not removed. The grain is then conveyed through one or more aspirating devices. Like those used in the initial scalping step, these devices utilize air jets to remove dust particles, dirt, and chaff. Since no aspirator is 100% efficient, several are used to assure as complete a separation as possible.

The grain then goes to a disc separator. The main feature of this machine is its unique set of rotating discs. Each disc contains many specially designed grooves or pockets which trap and lift away foreign seeds, such as weed seeds, while allowing the grain to pass unhindered. Different plates are used to trap different kinds of seeds. The discs are positioned at right angles to the flow of grain and the machine is designed so that grain may be withdrawn at any point.

From here, the grain passes on to a scourer. This machine removes dirt from the surface of the wheat by friction. Designs vary, but usually the wheat is pushed against a hard emery surface by paddles, the severity of the operation being controlled by the clearance between the paddles and the emery surface. Scouring is often preceded by a light pre-wash to help toughen the grain and prevent it from being broken during the scouring process. Dirt and pieces of the outer coating of the wheat bran called beeswing generated during the scouring process are removed by air aspiration in the same way as outlined above.

The last cleaning operation performed on the grain is a water wash. The water removes any dirt still remaining on the grain and acts as a final separating device for any stones or bits of metal which may have remained throughout the cleaning process. Again, designs vary, but usually the grain is conveyed through a trough of water. The dirt is floated away, and the metal and small stones sink. Excess water is removed from the grain by centrifugal action and the wheat is sent to the mill for grinding.

NATURE OF THE PARTICULATE EMISSION

The discharge from a grain cleaning house consists of dust and other particles developed during the cleaning process or carried in as dockage, as shown in Table 32. Dockage is defined as that material in the grain which is of no use and must be removed. This includes chaff, dirt, sticks, stones, cloth, paper, insect debris, foreign seeds, and so on. Any of these materials, if fine enough, will yield air-borne dust upon agitation of the grain. Since the cleaning process, by its very nature, agitates the grain vigorously, much dust is released in the process. Table 33 lists some of the properties of the dust emitted during the cleaning process. The quantity of dust generated depends, of course, upon the size of the operation and upon such factors as grain type, quality, and the amount of dockage present. As is to be expected, different pieces of equipment in the cleaning process emit different concentrations of dust. However, usual practice is to duct the individual dust sources to a common dust collector. Based on emission test measurements in about 600 grain cleaning operations, average emission estimates from various kinds of grain cleaning equipment have been made. These emissions, measured as dust load to the control device, range from a high of 9.9 gr/SCF from the scourer in an air volume of 2350 ACFM to a low of 1.45 gr/SCF from the wheat cleaning separator in an air volume of 8,000 ACFM. Other pieces of equipment tested were the scalper and the wheat cleaning aspirator which had dust loads of 3.2 and 2.32 gr/SCF in an average of 2,950 ACFM and 5,000 ACFM, respectively.

In addition to the common dust collector operation, some pieces of equipment, such as the aspirator, operate on a closed system basis. The same air is used repeatedly, cleaned and recirculated, and never escapes to the atmosphere[8]. This report will focus on equipment which is not of the closed system type.

POLLUTION CONTROL CONSIDERATIONS

The two types of pollution control equipment most commonly used in conjunction with grain cleaning operations are fabric filters and cyclones.

As mentioned above, common practice is to provide a dust collection system common to many pieces of equipment. Therefore, the cleaning house may be served by a single appropriately sized fabric filter or bank of cyclones. To keep dust emissions to a minimum, machines are usually closed to the atmosphere and under negative pressure so that dust generated in the cleaning process is kept within the machine and carried by the ductwork to the collection system.

Both cyclones and fabric filters are in wide use in the feed and grain industry. Table 34 shows a comparison of these two types of control devices. Where compliance with relevant codes can be achieved with cyclones, economics will dictate their use. However, cyclones have limited efficiency capability and cannot achieve compliance in all cases. Where cyclones cannot be used, fabric filters are the most common control device employed. Fabric filter efficiencies are, in most cases,

TABLE 32

CONTAMINANTS GENERATED DURING GRAIN CLEANING

Operation	Type of Contaminant Generated
Inclined Sieve	Dust, dirt, chaff
Aspirator	Dust, dirt, chaff
Disc Separator	Foreign seeds, dust
Scourer	Dirt, beeswing
Conveyors	Dust

TABLE 33

PROPERTIES OF DUST EMITTED FROM GRAIN CLEANING OPERATIONS

Particle Size	Ranges[3] from 1μ to 1000μ Larger particles such as chaff and insect debris may also be present
Dust Concentration	Ranges[4] from about 1 to 10 gr/SCF
Specific Gravity	1.8 for both the primary cyclone and secondary fabric filter catch
Temperature	Ambient
Moisture Content of Dust	Moisture content of the air due to ambient relative humidity

TABLE 34

RELATIVE ADVANTAGES AND DISADVANTAGES OF CYCLONES AND FABRIC FILTERS

Unit	Advantages	Disadvantages
Fabric Filters	1. High single unit efficiency.	1. High maintenance cost, i.e., bag replacement.
	2. With the right filter fabric, efficiencies remain high for small particles.	2. High first cost.
Cyclones	1. Low first cost.	1. Single unit efficiencies low especially for small particles, requiring cascading.
	2. Low maintenance cost.	

more than adequate to achieve compliance with all applicable codes.

SPECIFICATIONS AND COSTS

Specifications have been written for fabric filter systems to collect the dust emitted from the operations of both a small and a large grain cleaning house processing wheat. The fabric filter is specified to treat a single air exhaust stream which has been ducted from the hoods of the following grain cleaning operations:

1. Scalping
2. Aspiration
3. Disc separation
4. Scouring

Equipment specifications are shown in Tables 35 and 36 and cost data for the systems are shown in Tables 37 and 38 and Figures 26 and 27. The bidders specified different but standard fabric filter materials and average air to cloth ratios of about 10/1 for both small and large sized operations, respectively.

To minimize the explosion hazard associated with grain cleaning operations, a number of fabric filter safety features were considered. Explosion vents are standard on all grain house fabric filters and are included in the gas cleaning device cost. While spark proof fan wheels are sometimes used to minimize explosion danger, they are not normally required since they are on the clean air side of the fabric filter. Consequently, this feature was not included in the bids.

TABLE 35

FABRIC FILTER PROCESS DESCRIPTION FOR GRAIN CLEANING HOUSE SPECIFICATION

A fabric filter system is to treat the dust emitted from the grain cleaning operations in a grain cleaning house. These cleaning operations include the following:

1. *Scalping*
2. *Aspiration*
3. *Disc Separation*
4. *Scouring*

The hoods from all of these operations are to be ducted together to provide a single common air exhaust stream which will be treated by the fabric filter.

The vendor is to furnish a pulse-type fabric filter unit, hoppers equipped with rotary air locks, required booster fan, and all controls. The vendor is also to supply the required hoods and ductwork in accordance with the information shown below:

A. Small (227 bu/hr) plant.

Operation	*Ventilation Rate ACFM*	*Hood Area ft²*	*Duct Velocity fpm*
Scalping	*4,000*	*16*	*3,500*
Aspiration	*6,000*	*24*	*3,500*
Disc Separation	*2,000*	*8*	*3,500*
Scouring	*3,000*	*12*	*3,500*
	15,000	*60*	

B. Large (758 bu/hr) plant.

Operation	*Ventilation Rate ACFM*	*Hood Area ft²*	*Duct Velocity fpm*
Scalping	*12,000*	*48*	*3,500*
Aspiration	*18,000*	*72*	*3,500*
Disc Separation	*6,000*	*24*	*3,500*
Scouring	*9,000*	*35*	*3,500*
	45,000	*180*	

All common ductwork will be designed for a velocity of 3,500 fpm.

TABLE 36

FABRIC FILTER OPERATING CONDITIONS FOR GRAIN CLEANING HOUSE SPECIFICATION

	Small	Large
Cleaning House Capacity, bu/hr	227	758
Cleaning House Process Weight, lb/hr	12,500	41,700
Adjacent Flour Mill Capacity, cwt/day	2,400	9,000
Inlet Gas to Fabric Filter		
ACFM	15,000	45,000
Temperature, °F	75	75
SCFM	14,900	44,600
Solids Loading		
gr/ACF	3.02	3.32
lb/hr	388	1,281
Outlet Gas from Fabric Filter		
ACFM	15,000	45,000
Temperature, °F	75	75
SCFM	14,900	44,600
Solids Loading		
gr/ACF	0.01	0.01
lb/hr	1.29	3.86
Collection Efficiency	99.6	99.7

TABLE 37

ESTIMATED CAPITAL COST DATA (COST IN DOLLARS) FOR FABRIC FILTERS FOR GRAIN CLEANING HOUSE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			15,000	45,000
°F			75	75
SCFM			14,900	44,600
Moisture Content, Vol. %				
Effluent Contaminant Loading				
gr/ACF			3.02	3.32
lb/hr			388	1,281
Cleaned Gas Flow				
ACFM			15,000	45,000
°F			75	75
SCFM			14,900	44,600
Moisture Content, Vol. %				
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			1.29	3.86
Cleaning Efficiency, %			99.6	99.7
(1) Gas Cleaning Device Cost			12,364	29,493
(2) Auxiliaries Cost				
(a) Fan(s)			4,537	12,910
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment			1,821	3,212
(3) Installation Cost			28,825	62,030
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			47,547	107,645

FIGURE 26

CAPITAL COST OF FABRIC FILTERS FOR GRAIN CLEANING HOUSE

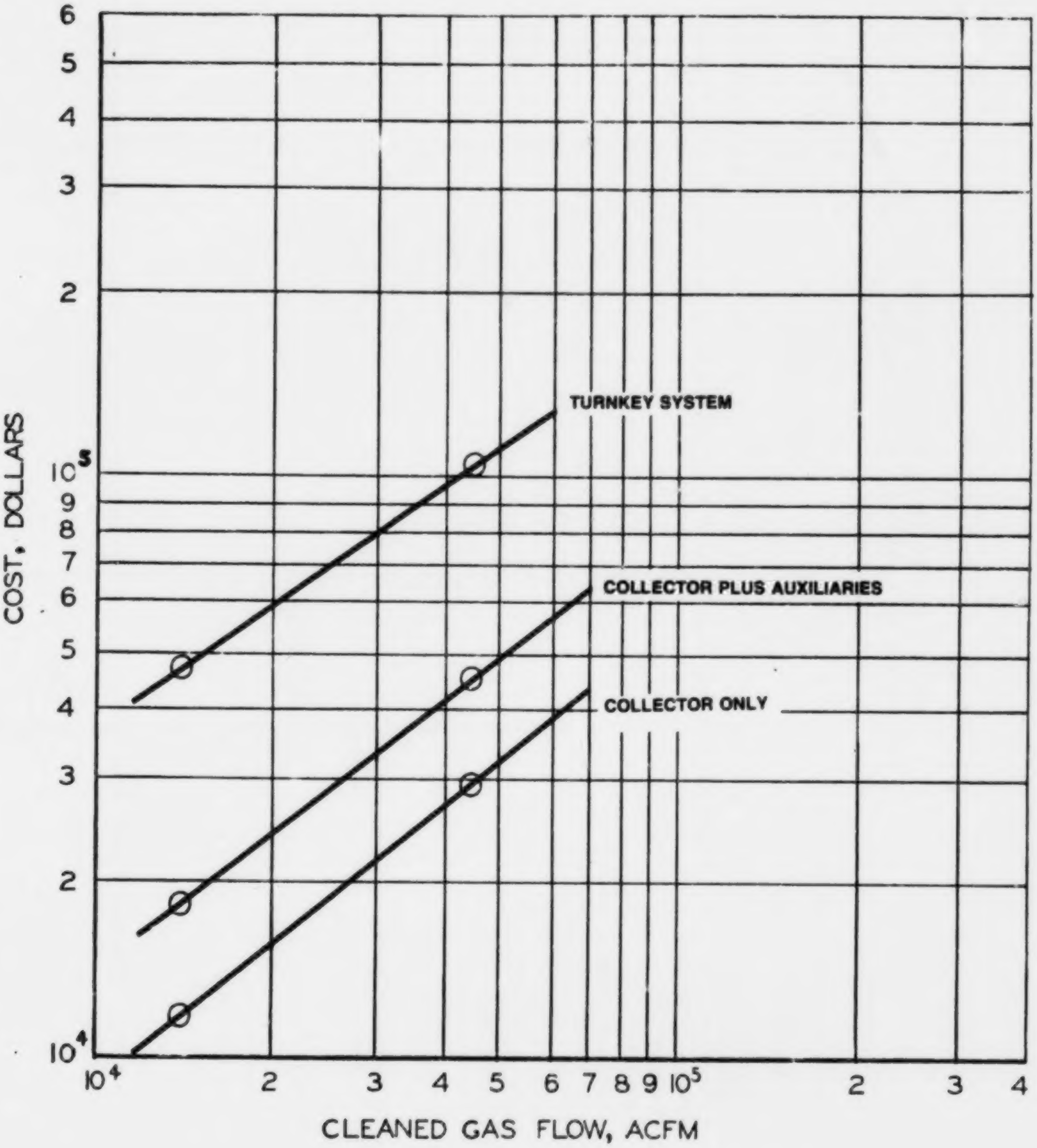


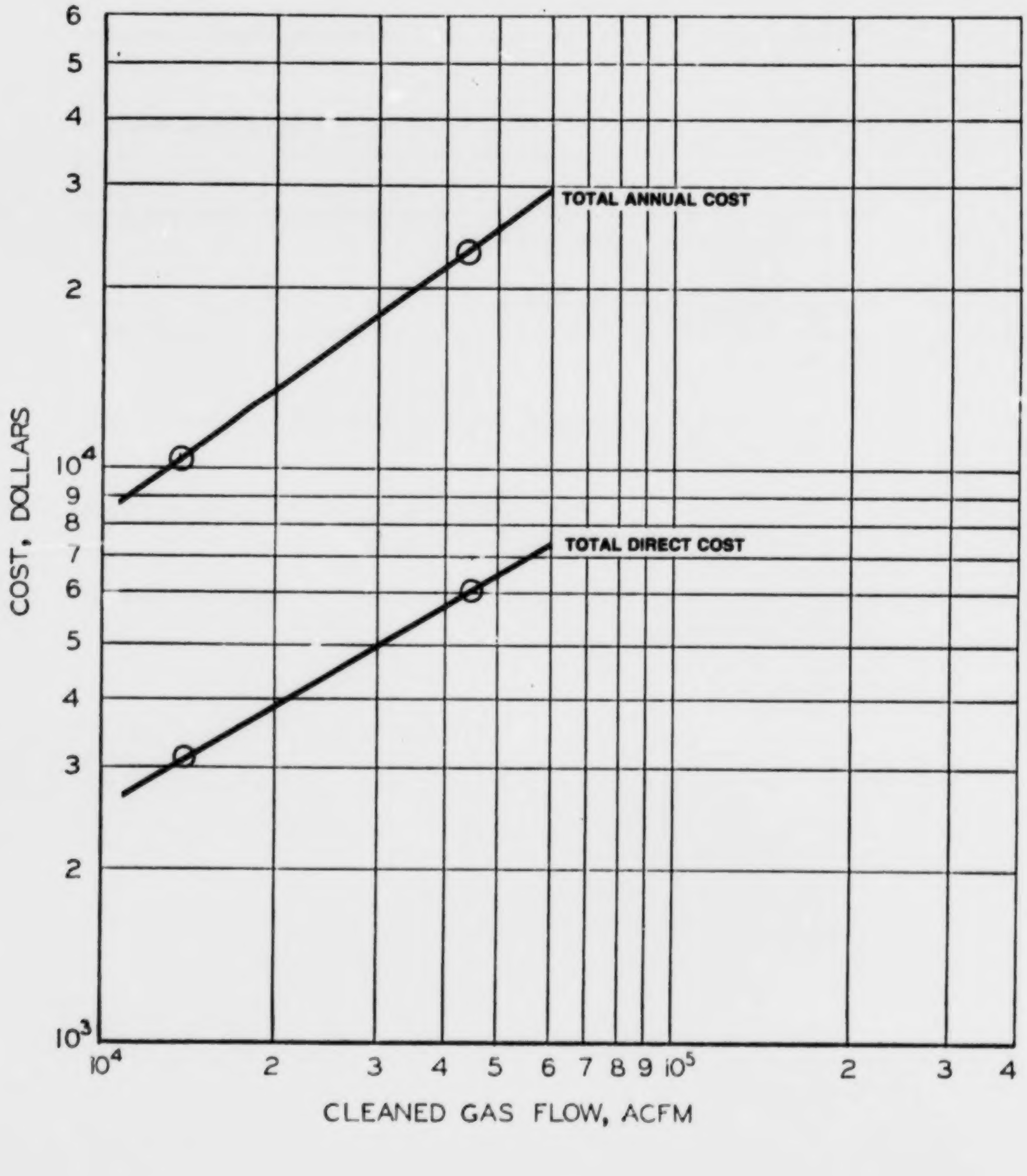
TABLE 38

ANNUAL OPERATING COST (COST IN $/YEAR) FOR FABRIC FILTERS FOR GRAIN CLEANING HOUSE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year -4000					
Operating Labor (if any)					
Operator	$6/mh				
Supervisor	$8/mh			None	None
Total Operating Labor					
Maintenance					
Labor	$6/mh			1,068	1,410
Materials				125	150
Total Maintenance				1,193	1,560
Replacement Parts				775	1,575
Total Replacement Parts				775	1,575
Utilities					
Electric Power	$0.011/kwh			1,142	2,876
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities				1,142	2,876
Total Direct Cost				3,110	6,011
Annualized Capital Charges	16% of Cap.			7,608	17,223
Total Annual Cost				10,718	23,234

FIGURE 27

ANNUAL COST OF FABRIC FILTERS FOR GRAIN CLEANING HOUSE



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4. GLASS-MELTING FURNACES

Glass is an inorganic product of fusion which has been cooled to a rigid condition without crystallizing. Commercial glasses are produced from inorganic oxides, of which silica, or sand, is usually an important constituent. Glass is made by heating a mixture of dry materials to about 2800°F in a refractory container. The heating is continued until a viscous, homogeneous liquid is formed. By varying the proportions of the raw materials, glasses can be produced with physical and chemical properties which vary over wide ranges.

Glasses are mixtures rather than compounds of various oxides. The common oxides in glass are classified as formers, stabilizers and fluxes. Only a limited number of chemical compounds are capable of forming the three-dimensional random atomic structure characteristic of glass. The common glass formers are the oxides of silicon (SiO_2), boron (B_2O_3), and phosphorous (P_2O_5). The melting point and working temperature of the mixture are lowered by adding fluxes, which decrease the viscosity of the mixture. Stabilizers are added to improve chemical durability and/or to prevent crystallization.

About 700 different types of glasses are produced commercially each year. Of these glasses, a small number are produced in great volume because they have good all-around usefulness. These glasses, which comprise the bulk of commercial production, are commonly classified in the following chemical types of silicate glass:

1. soda-lime glass
2. lead glass
3. borosilicate glass
4. 96 percent silica glass
5. 99.8 percent silica glass, i.e., fused quartz or fused silica.[1]

The composition ranges of these commercial types are given in Table 39. Soda-lime glass presently constitutes about 90 percent of the total production of commercial glass.[3]

Non-silicate glass forming systems are used to a much lesser extent. For example, phosphate glasses are used as high temperature lubricants; iron glasses are used in heat-absorbing applications; and borate glasses are used in sodium vapor lamps.

Other types of silicate glasses, such as colored, opal, and optical, are usually made from the five basic types of silicate glass listed in Table 39. Colored glasses are generally made by adding traces of metallic oxides to the batch, plus proper heat treatment of the finished glass. Opal glasses, which are

TABLE 39

APPROXIMATE COMPOSITIONS OF COMMERCIAL GLASSES[3]

	Soda-lime Wt %	Lead Wt %	Borosilicate Wt %	96% Silica Wt %	99.8% Silica Wt %
SiO_2	70-75	53-68	73-82	96	99.8
Na_2O	12-18	5-10	3-10		
K_2O	0-1	1-10	0.4-1		
CaO	5-14	0-6	0-1		
PbO	—	15-40	0-10		
B_2O_3	—	—	5-20	3	
Al_2O_3	0.5-2.5	0-2	2-3		
MgO	0-4	—	—		

translucent silicas of various colors, capable of refracting light and then reflecting it in a play of colors, are usually made by adding fluorides or phosphates to the batch. Optical glasses are made in a variety of compositions. In general, the chemical composition of other types of glasses does not vary significantly from that of the five basic types.

Over 5,000,000 tons of glass sand are used in the United States each year in order to produce all of these various glasses. To flux this silica requires over 1,500,000 tons of soda ash, 113,000 tons of salt cake (impure sodium sulfate, 90 to 99%), and 875,000 tons of limestone or equivalent lime.[5]

Sand for glass manufacture should be almost pure quartz. The location of glass factories is frequently determined by the location of glass-sand deposits. Soda, Na_2O, is supplied mainly by dense soda ash, Na_2CO_3. Other sources are sodium bicarbonate, sodium sulfate, and sodium nitrate. The primary sources of lime, CaO, are limestone and burnt lime from dolomite.

The chemical reactions involved in making glass may be summarized as follows:[5]

$$Na_2CO_3 + aSiO_2 \rightarrow Na_2O \cdot aSiO_2 + CO_2 \qquad (1)$$
$$CaCO_3 + bSiO_2 \rightarrow CaO \cdot bSiO_2 + CO_2 \qquad (2)$$
$$Na_2SO_4 + cSiO_2 + C \rightarrow Na_2O \cdot cSiO_2 + SO_2 + CO \qquad (3)$$

The last reaction may take place as in equations (4) or (5), and (6):

$$Na_2SO_4 + C \rightarrow Na_2SO_3 + CO \qquad (4)$$
$$2Na_2SO_4 + C \rightarrow 2Na_2SO_3 + CO_2 \qquad (5)$$
$$Na_2SO_3 + cSiO_2 \rightarrow Na_2O \cdot cSiO_2 + SO_2 \qquad (6)$$

The ratios Na_2O/SiO_2 and CaO/SiO_2 need not be 1 to 1 molecular ratios. In ordinary window glass the molecular ratios are approximately:

2 mols Na_2O/5 mols SiO_2 and 1 mole CaO/5 moles SiO_2

Other glasses vary widely.[5]

PROCESS DESCRIPTION

There are two basic steps in the manufacture of glass. They are:

1. The melting of sand and stabilizing oxides to form molten glass
2. The fabrication of this molten glass into useful articles

In the first step, sand and other raw materials are procured and stored in sufficient quantities to permit continuity of operation. These materials are accurately weighed in correct proportions to yield glass of the desired composition. Then they are thoroughly mixed and fed into the melting furnace. In the melter the raw materials are heated to a higher temperature until chemical reactions which liberate carbon dioxide, water, and other gases are completed, and the bubbles thus formed are eliminated. The glass is cooled, before leaving the melting unit, to bring its viscosity to a value that is suitable for the particular forming operation to be used. Table 40 presents the useful range of glass viscosities with regard to its use in a particular manufacturing operation.

Fabrication of the molten glass may involve such operations as pressing, blowing, rolling or drawing. After the glass is formed to a particular shape, the article passes through an annealing oven to reduce internal stress.

Secondary, or finishing, operations such as grinding, polishing, cutting and chemical treatment are frequently performed on the fabricated articles. In most instances, such operations are separated from the primary fabrication operations and sometimes occur in a plant of an entirely different organization.

The factors involved in the selection of sand, and other materials as well, are purity, cost, and grain size. The principal ingredients used for manufacturing soda-lime glass are sand, soda ash, and limestone. Other materials frequently used in glass production are borax, boric acid, litharge, potash, fluorspar, zinc oxide, and barium carbonate. Table 41 lists several of the raw constituents of glass and their glassmaking equivalents.

Most glass is melted by a continuous process in tanks made of refractory blocks and heated from above by the flames of burning fuel. Batch or day tanks are used for small amounts of glass, having special composition and properties. The batch type units reach sizes of a few tons in holding capacity, while continuous tanks range from less than a ton to 1500 tons capacity, with outputs up to several hundred tons of glass per day.

Continuous tanks for melting glass are generally rectangular in shape and are divided into two compartments by a permanent wall or by floating refractory baffles. The batch of well-mixed raw materials is introduced into the larger compartment known as the melting end. The other compartment, known as the working or refining end, is where the glass is cooled and distributed for use.

In the melting end of the tank, the batch is heated until the

TABLE 40

USEFUL RANGE OF GLASS VISCOSITIES[1]

Operation	Viscosity, Poises
Melting	10^{2}
At Automatic Feeder	10^{3} - 10^{4}
For hand gathering	$10^{3.2}$
Gather when placed in paste mold	$10^{4.5}$
Ware removed from paste mold	10^{7}
Annealing	10^{13} - $10^{13.5}$
At maximum service temperature (Temperature at which glass is substantially rigid)	$10^{14.6}$ - $10^{15.5}$

TABLE 41

GLASSMAKING MATERIALS[1]

Raw Material	Chemical Composition	Glassmaking Oxide	Percent Oxide
Sand	SiO_2	SiO_2	100.0
Soda Ash	Na_2CO_3	Na_2O	58.5
Limestone	$CaCO_3$	CaO	56.0
Dolomite	$CaCO_3 \cdot MgCO_3$	CaO	30.4
		MgO	21.8
Feldspar	$K_2(Na_2)O \cdot Al_2O_3 \cdot 6SiO_2$	Al_2O_3	18.0
		$K_2(Na_2)O$	13.0
		SiO_2	68.0
Borax	$Na_2B_4O_7 \cdot 10H_2O$	Na_2O	16.3
		B_2O_3	36.5
Boric Acid	$B_2O_3 \cdot H_2O$	B_2O_3	56.3
Litharge	PbO	PbO	100.0
Potash	$K_2CO_3 \cdot 1.5H_2O$	K_2O	57.0
Fluorspar	CaF_2	CaF_2	100.0
Zinc Oxide	ZnO	ZnO	100.0
Barium Carbonate	$BaCO_3$	BaO	77.7

fluxes melt and dissolve the sand and other ingredients. Carbon dioxide and water, as well as air trapped in the interstices of the batch, produce many bubbles so that when first melted, the glass is a foamy mass. Most of these bubbles are eliminated at the high temperature of the melting end. Convection currents, which arise in the glass through the heating of the flames and cooling by side walls and cold batch, help to make the melt homogeneous by a stirring action. The molten glass from the melting end passes through a hole, or throat, in the wall, or under the floating refractory baffles. This serves to skim off foam or scum on the surface of the molten glass.

In the refining end of the tank, the glass is cooled until its viscosity has increased to the proper value for fabrication. In mechanized operations, the glass flows from the refining end to the forming equipment in refractory channels termed "forehearths." The final cooling takes place in the forehearths, the construction of which vary depending upon the kind of forming machine to be supplied. A flow diagram for soda-lime glass manufacture is presented in Figure 28.

Systems for batch mixing and conveying of materials for making soda-lime glass normally use commercial equipment of standard design. This equipment is generally separate from the glass-melting furnace and is commonly referred to as a "batch plant." A flow diagram of a typical batch plant is shown in Figure 29. Major raw materials and cullet (broken scrap glass) are conveyed to the elevated storage bins from railroad hopper cars or hopper trucks by a combination of screw conveyors, belt conveyors, and bucket elevators. Minor ingredients are usually delivered in cardboard drums and transferred by hand to small bins. The ingredients for a given batch are dropped from the storage bins into weigh hoppers and then released into the mixer. Cullet is ground and then mixed with the other ingredients in the mixer. These materials are blended for 3 to 5 minutes and then transferred to a charge bin located near the melting furnace. The blended material is fed into the furnace feeders through rotary valves located at the bottom of the charge bin.

Glass-melting furnaces for soda-lime glass are generally direct-fired, continuous, regenerative furnaces. They usually range in capacity from 50 to 300 tons of glass per day. The most common capacity found in the United States is 100 tons per day.[3] Regenerative firing systems consist of dual chambers filled with brick checkerwork. Combustion air is preheated in one chamber, while the products of combustion from the melter pass through and heat the opposite chamber. By reversing the flow of air and combustion products, the functions of each chamber are interchanged. This occurs every 15 to 20 minutes in order to maximize heat conservation.

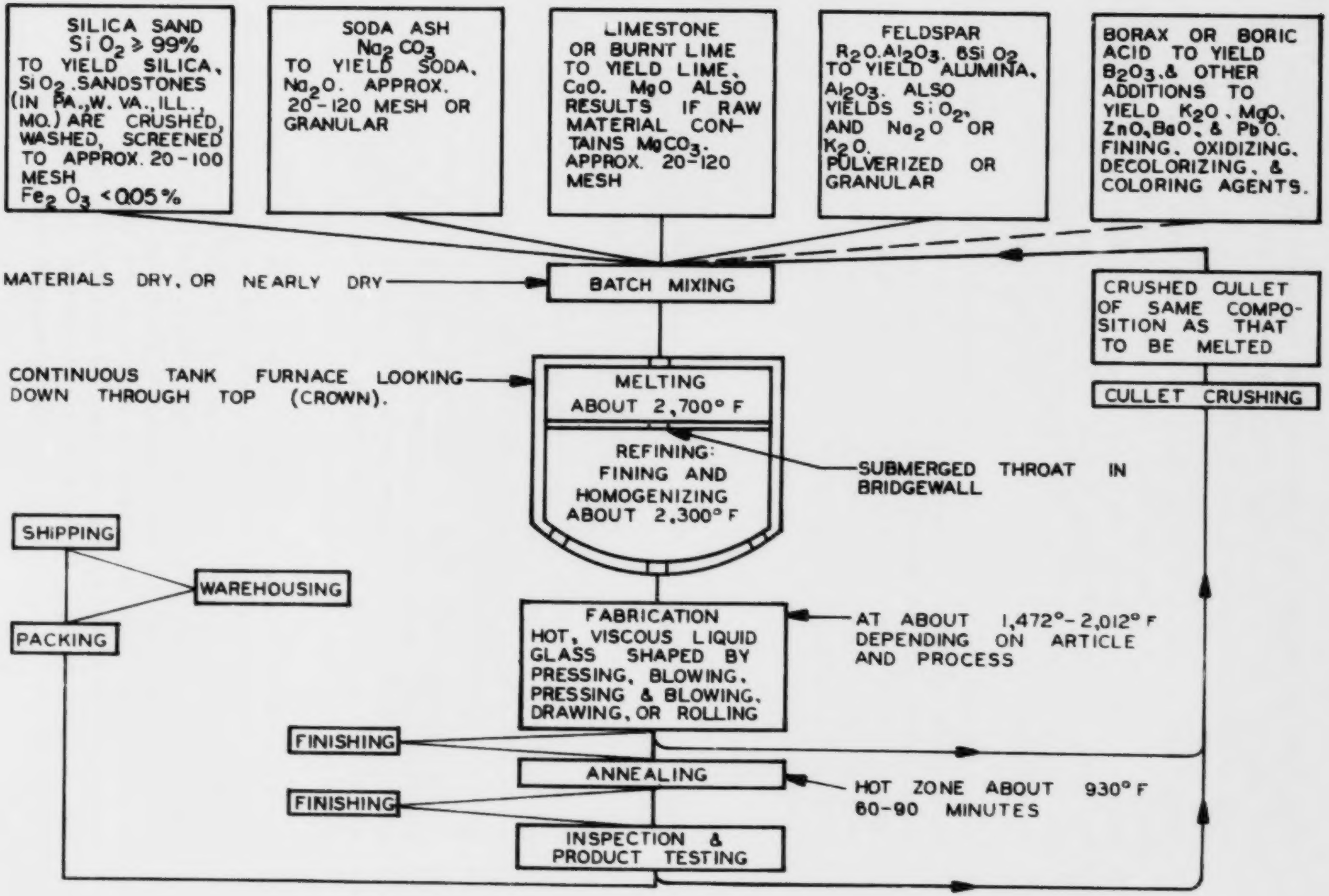

SILICA SAND
$SiO_2 \geq 99\%$
TO YIELD SILICA, SiO_2. SANDSTONES (IN PA., W. VA., ILL., MO.) ARE CRUSHED, WASHED, SCREENED TO APPROX. 20-100 MESH
$Fe_2O_3 < 0.05\%$
SODA ASH
Na_2CO_3
TO YIELD SODA, Na_2O. APPROX. 20-120 MESH OR GRANULAR
LIMESTONE OR BURNT LIME TO YIELD LIME, CaO. MgO ALSO RESULTS IF RAW MATERIAL CONTAINS $MgCO_3$. APPROX. 20-120 MESH
FELDSPAR
$R_2O.Al_2O_3.6SiO_2$ TO YIELD ALUMINA, Al_2O_3. ALSO YIELDS SiO_2, AND Na_2O OR K_2O.
PULVERIZED OR GRANULAR
BORAX OR BORIC ACID TO YIELD B_2O_3, & OTHER ADDITIONS TO YIELD K_2O, MgO, ZnO, BaO, & PbO. FINING, OXIDIZING, DECOLORIZING, & COLORING AGENTS.
MATERIALS DRY, OR NEARLY DRY
BATCH MIXING
CRUSHED CULLET OF SAME COMPOSITION AS THAT TO BE MELTED
CULLET CRUSHING
CONTINUOUS TANK FURNACE LOOKING DOWN THROUGH TOP (CROWN).
MELTING
ABOUT 2,700° F
REFINING:
FINING AND HOMOGENIZING
ABOUT 2,300° F
SUBMERGED THROAT IN BRIDGEWALL
SHIPPING
WAREHOUSING
PACKING
FABRICATION
HOT, VISCOUS LIQUID GLASS SHAPED BY PRESSING, BLOWING, PRESSING & BLOWING, DRAWING, OR ROLLING
AT ABOUT 1,472°-2,012° F DEPENDING ON ARTICLE AND PROCESS
FINISHING
ANNEALING
HOT ZONE ABOUT 930° F
60-90 MINUTES
FINISHING
INSPECTION & PRODUCT TESTING

FIGURE 28

FLOW DIAGRAM FOR SODA-LIME GLASS MANUFACTURE[3]

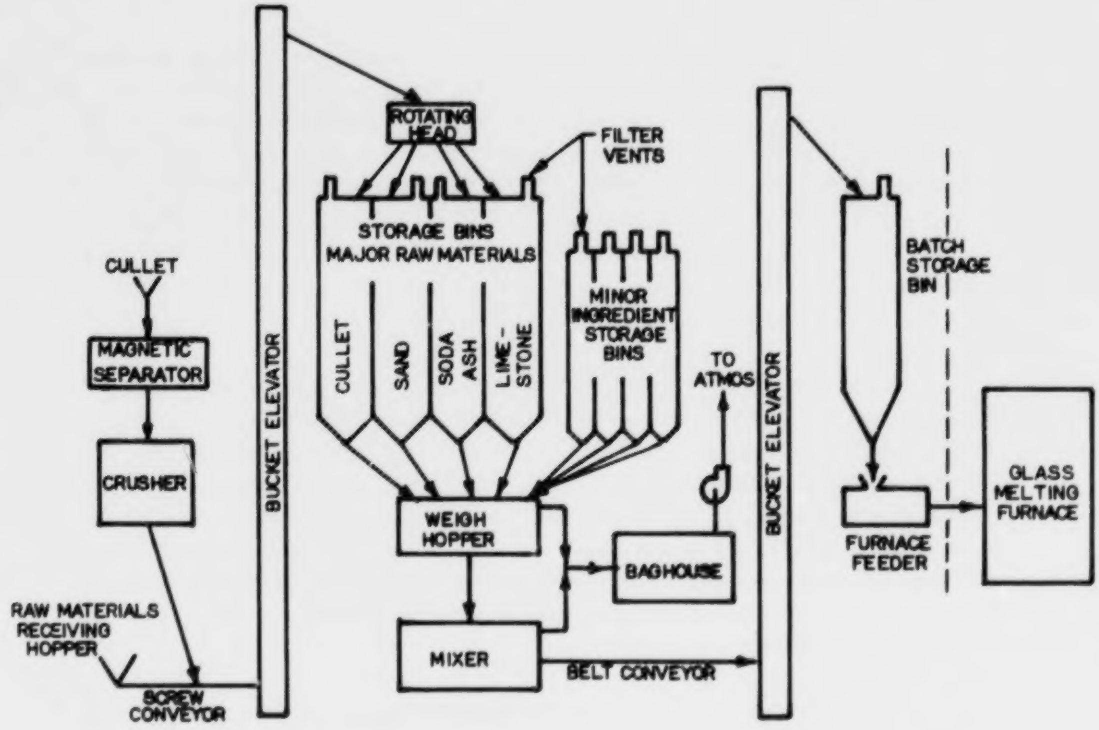

ROTATING HEAD
FILTER VENTS
STORAGE BINS MAJOR RAW MATERIALS
CULLET
MAGNETIC SEPARATOR
CRUSHER
BUCKET ELEVATOR
CULLET
SAND
SODA ASH
LIME-STONE
MINOR INGREDIENT STORAGE BINS
TO ATMOS
BUCKET ELEVATOR
BATCH STORAGE BIN
GLASS MELTING FURNACE
WEIGH HOPPER
BAGHOUSE
FURNACE FEEDER
RAW MATERIALS RECEIVING HOPPER
MIXER
BELT CONVEYOR
SCREW CONVEYOR

FIGURE 29

PROCESS FLOW DIAGRAM OF A BATCH PLANT[3]

In order to prevent air induction and a subsequent loss in combustion efficiency, continuous furnaces are usually operated slightly above atmospheric pressure. Furnace draft is produced by induced-draft fans, natural-draft stacks, or ejectors.

NATURE OF THE GASEOUS DISCHARGE

Melting Furnaces

The major source of air contaminants from a glass plant is the glass-melting furnace. An estimate of national pollutant emissions from glass furnaces based upon production in 1971 is presented in Table 42. During the melting process, carbon dioxide bubbles form and propel particulates from the melting batch. These particulates are entrained by the fast-moving stream of flames and combustion gases. Once swept from the melter, they are either collected in the checkerwork and gas passages or exhausted to the atmosphere. Particulate emissions are also formed due to the condensation of certain components which were volatized in the glass melt.

Many source tests of glass furnaces in Los Angeles County were studied to determine the major variables which influence stack emissions, and this data is summarized in Table 43. Particulate samples were obtained from the catch of a pilot fabric filter which vented part of the effluent from a large soda-lime container furnace,[3] and particle size distributions of two typical samples are shown in Table 44. Additional particle size distributions from a separate study of two side-port, regenerative, gas-fired furnaces are presented in Figure 30. Flue gas conditions and compositions during sampling for these additional tests are shown in Tables 45 and 46.

The chemical compositions of five separate particulate samples, four from a pilot fabric filter, and one from the stack of a soda-lime regenerative furnace, are presented in Table 47. These samples were found to be composed mostly of alkali sulfates although alkalies are reported as oxides.

Opacity of stack and particulate emissions did not correlate very well, based on the source test data presented in Table 43. However, some generalizations on opacity can be made.

1. Opacity increased directly with particulate loading
2. Furnaces burning U. S. Grade 5 fuel oil usually have plumes exceeding 40% opacity.
3. While burning natural gas or U. S. Grade 3 fuel oil, however, the plumes from these same furnaces are only 15 to 30 percent white opacity.

TABLE 42

ESTIMATED NATIONAL EMISSIONS, 1971 (TONS)

GLASS FURNACES[4]

Sulfur Oxides	1,675
Nitrogen Oxides	1,125
Carbon Monoxide	2,350
Fluorides	275
Particulate Matter	26,250

TABLE 43

SOURCE TEST DATA FOR GLASS-MELTING FURNACES[3]

Test No.	Type of Furnace*	Type of Fuel**	X_1 (particulate emissions), lb/hr	X_2 (process wt ratio), lb/hr ft² of Melter Area	X_3, wt fraction of cullet in Charge***	X_4 (checker volume), ft³/ft² of Melter	Maximum Opacity of Stack Emissions, %
C-339b	EP	0-300	7.00	16.7	0.300	5.40	50
C-339	EP	G	3.00	13.8	0.300	5.40	10
C-382-1	EP	G	4.60	16.5	0.300	5.40	10
C-382-2	EP	G	6.40	18.2	0.300	5.40	10
C-536	EP	0-200	4.70	17.5	0.199	5.40	10
C383	EP	G	8.40	17.9	0.300	6.50	20
Pri-Lab	EP	G	3.86	10.9	0.094	8.00	25
Pri Lab	EP	G	4.76	14.6	0.094	8.00	25
Pri Lab	EP	G	4.26	17.1	0.157	8.00	25
Pri Lab	EP	G	6.84	17.4	0.094	8.00	25
Pri Lab	EP	G	4.62	18.5	0.365	9.00	—
Pri Lab	EP	0-300	3.96	14.6	0.269	9.00	45
Pri Lab	EP	G	7.16	20.2	0.175	9.00	20
C-101	EP	G	9.54	15.2	0.300	5.00	20
C-120	EP	G	9.90	14.2	0.320	5.00	20
C-577	SP	0-300	12.70	24.2	0.134	6.90	35
C-278-1	SP	G	3.97	18.3	0.361	6.93	20
C-278-2	SP	0-300	8.44	18.5	0.360	6.93	20
C-653	SP	G	8.90	22.0	0.131	8.74	40
C-244-1	SP	G	6.30	7.5	0.182	7.60	25
C-244-2	SP	G	3.00	5.4	0.100	7.60	25
C-420-1	SP	G	6.30	10.7	0.100	7.60	10
C-420-2	SP	G	6.60	13.2	0.100	7.60	5
C-743	SP	G	10.20	26.2	0.047	8.25	25
C-471	SP	G	6.70	11.6	0.276	5.60	30

*EP = end port, regenerative furnace; SP = side port, regenerative furnace.

**G = natural gas; 0-200 = U.S. Grade 3 fuel oil; 0-300 = U.S. Grade 5 fuel oil.

***Constants: Sulfate content of charge 0.18 to 0.34 wt %. Fines (-325 mesh) content of charge 0.2 to 0.3 wt%.

TABLE 44

SIZE DISTRIBUTION OF PARTICULATE EMISSIONS[3]
(Micromerograph Analyses)

Furnace 1 — Flint Glass		Furnace 2 — Amber Glass	
Diameter (D), μ	% (by wt) Less Than D	Diameter (D), μ	% (by wt) Less Than D
36.60	100	17.40	100
22.0	99.5	15.70	99.8
18.30	98.6	14.00	99.4
16.50	97.7	12.20	96.8
14.60	94.0	11.60	92.5
12.80	84.6	11.00	89.5
12.20	80.7	10.50	87.2
11.60	76.6	9.90	83.4
11.00	72.7	9.30	78.7
10.40	67.7	8.80	75.0
9.80	62.4	8.10	73.4
9.20	58.3	7.00	60.3
8.50	51.8	5.80	47.6
7.30	43.1	4.65	35.6
6.10	34.4	3.49	25.4
4.88	28.0	2.91	20.5
3.66	21.3	2.33	16.4
3.05	18.6	1.74	10.9
2.44	14.9	1.45	8.9
1.83	11.0	1.16	5.3
1.52	8.3		
1.22	4.1		

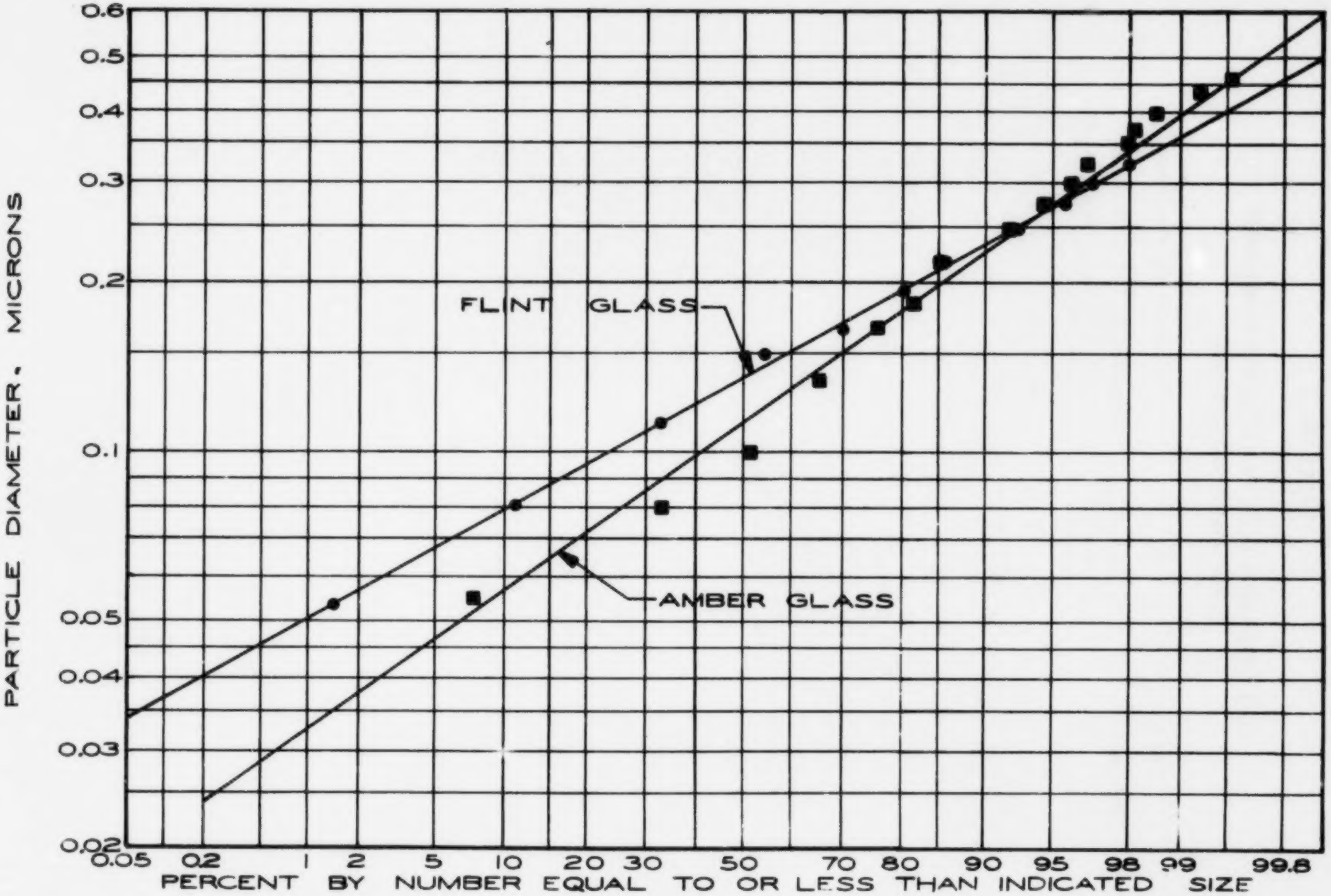


FIGURE 30. Log.-probability distribution of particle sizes present in glass furnace effluent.(2)

TABLE 45

FLUE CONDITIONS FROM THE MANUFACTURE OF GLASS[2]

	Flint Glass Furnace	Amber Glass Furnace
Flue diameter, ft	5	6
Average gas velocity, ft/sec	16	33
Average gas temperature, ° F	619	1,143
Static pressure, in. H_2O	− 0.44	− 0.98
Gas volume, scfm	8,250	16,800

TABLE 46

EMISSIONS FROM THE MANUFACTURE OF GLASS[2]

Emissions	Flint Glass Furnace	Amber Glass Furnace
Solids, gr/scf	0.029	0.041
Solids, lb/hr	2.1	5.4
Sulfur trioxide, ppm*	17	15
Sulfur dioxide, ppm	250	315
Fluorine, ppm	2.2	1.9
Nitrogen oxides, ppm	340	640
Carbon monoxide, ppm	375	40

*ppm by volume for all gaseous pollutants.

TABLE 47

CHEMICAL COMPOSITION OF PARTICULATE EMISSIONS
(Quantitative Analyses)

Metallic Ions Reported as Oxides[3]

Sample Source Test Type of Glass Components	Baghouse Catch No. 1 Amber, wt %	Baghouse Catch No. 2 Flint, wt %	Baghouse Catch No. 3 Amber, wt %	Baghouse Catch No. 4 Flint, wt %	Millipore* Filter No. 5 Flint, wt %
Silica (SiO_2)	0.03	0.3	0.1	4.1	3.3
Calcium oxide (C_aO)	1.70	2.3	0.8	19.2	
Sulfuric Anhydride (SO_3)	46.92	25.1	46.7	30.5	39.4
Borix Anhydride (B_2O_3)	3.67	1.3			
Arsenic Oxide (As_2O_3)	7.71				
Chloride (Cl)	0.01				
Lead Oxide (PbO)	0.39				
$K_2O + Na_2O$	29.47	28.1	26.1	36.5	39.2
AL_2O_3		3.5		0.2	
Fluoride		8.6			
Fe_2O_3			0.1	0.6	
MgO				1.4	
ZnO			0.5		
Unknown metallic oxide (R_2O_3)					6.5
Loss on ignition	10.10	30.8	25.7	7.5	11.6

*Stack test of baghouse exhaust

4. The plumes from furnaces with ejector draft systems will have lower opacities than furnaces with natural-draft stacks or induced-draft fans.[3]

Exhaust volumes from glass-melting furnaces can be computed from the fuel requirements on the basis of combustion with 40 percent excess combustion air. Figure 31 presents the fuel requirements for bridgewall-type, regenerative furnaces fired with natural gas. The information presented is based on furnaces constructed before 1955, which generally require more fuel per ton of glass than do furnaces constructed since 1955. Forty percent excess combustion air is chosen as representing average combustion conditions. The fuel requirements of container furnaces at maximum pull rates should be estimated by using a melter rating parameter of 4 square feet of melter surface area per daily ton of glass. For estimating the fuel requirements of non-bridgewall furnaces supplying glass for sheet, rod, and tube manufacture, a melter rating parameter of 8 should be used.

Exhaust volumes from furnaces with ejector systems are usually 30 to 40 percent greater than exhaust volumes from furnaces with natural-draft stacks or induced-draft fan systems. This is due to the ejector air, which is mixed in the ejector with the furnace effluent.

The temperature of exhaust gases from furnaces with natural-draft stacks or induced-draft fan systems usually ranges from 600 to 1,200°F depending upon many variables, including furnace age. Exhaust gas temperatures from furnaces with ejector systems are lower, varying from 400 to 600°F.

The exhaust gases from large, regenerative, gas-fired furnaces melting three kinds of soda-lime glass were analyzed. The results of the chemical analyses of the gaseous components produced are presented in Table 48.[3]

POLLUTION CONTROL CONSIDERATIONS

With regard to particulate emissions, it appears that most uncontrolled glass-melting furnace emissions are in, or very close to, compliance with federal regulations. However, when burning U. S. Grade 5 fuel oil, they usually have plumes exceeding 40 percent opacity. While burning natural gas or U. S. Grade 3 fuel oil, the plumes from these same furnaces are only 15 to 30 percent opacity.

In general, opacity is directly related to the amount of small sized particulate matter. There are many process variables that affect the emissions from

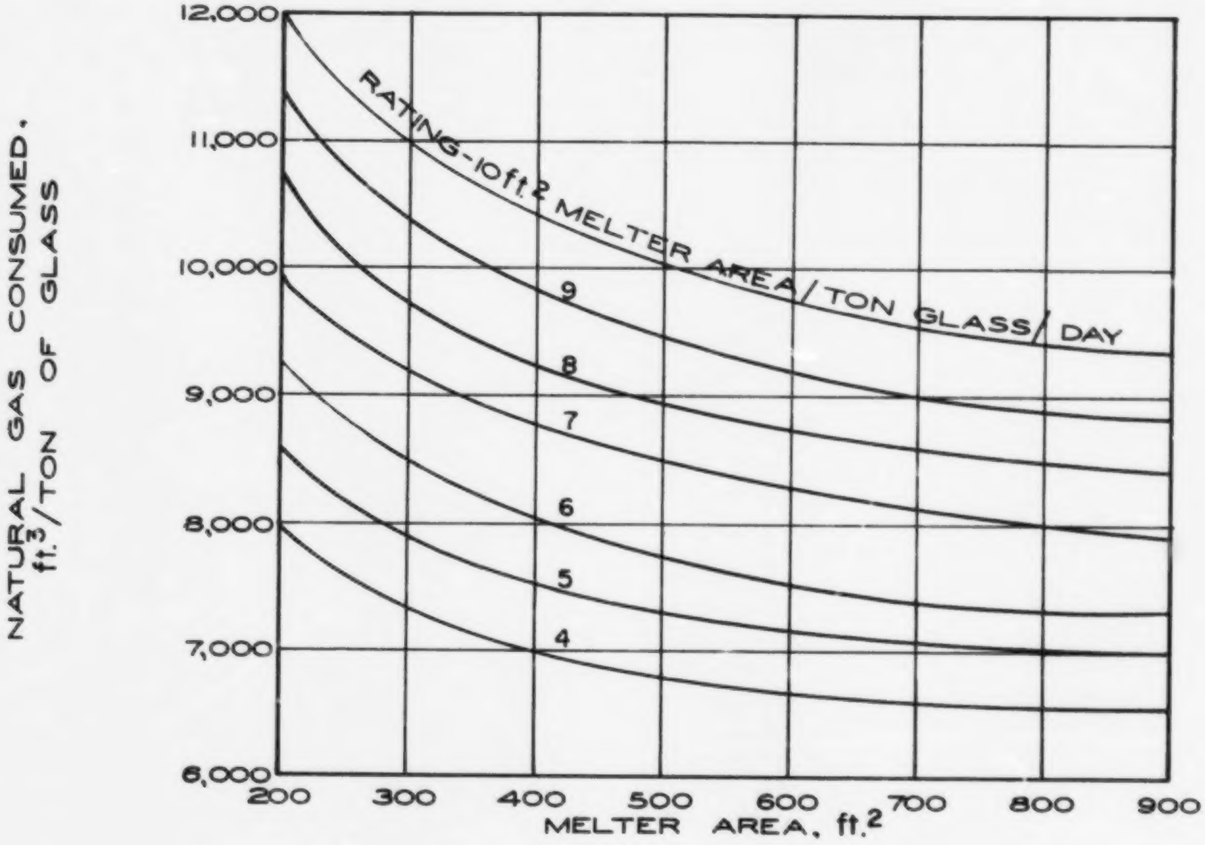


FIGURE 31

NATURAL GAS FOR BRIDGEWALL-TYPE REGENERATIVE FURNACES[3]

TABLE 48

CHEMICAL COMPOSITION OF GASEOUS EMISSIONS FROM GAS-FIRED, REGENERATIVE FURNACES[3]

Gaseous Components	Flint Glass	Amber Glass	Georgia Green
Nitrogen, vol %	71.9	81.8	72.5
Oxygen, vol %	9.3	10.2	8.0
Water vapor, vol %	12.4	7.7	12.1
Carbon dioxide, vol %	6.4	8.0	7.4
Carbon monoxide, vol %	0	0.007	0
Sulfur dioxide (SO_2), ppm	0	61	14
Sulfur trioxide (SO_3), ppm	0	12	15
Nitrogen oxides (NO, NO_2), ppm	724	137	NA
Organic acids, ppm	NA*	50	NA
Aldehydes, ppm	NA	7	NA

*NA = not available.

glass-melting furnaces. If these variables are changed as described below, they will tend to decrease particulate emissions:

1. Decrease the total sulfate (SO_4) content of the batch charge.
2. Decrease the quantity of <325-mesh fines in the batch charge.
3. Increase the cullet content of the batch charge.
4. Decrease the amount of fuel required to melt a ton of glass. (This variable is largely influenced by the mechanical design of the furnace, in particular, the checker design.)
5. Improve the combustion efficiency.
6. Improve regenerator efficiency by performing furnace reversals in relation to checker temperatures instead of at fixed periods of 15 to 20 minutes. This would serve to maximize the conservation of heat, and thereby minimize fuel consumption.

There has been little work done with regard to the application of pollution control systems to glass-melting furnace emissions. Fabric filters, electrostatic precipitators, and high energy Venturi scrubbers have been tested to a limited degree.

Electrostatic Precipitators

Electrostatic precipitators are suitable for collection of fine particles such as those emitted from glass furnaces. Costs, however, tend to be high for small gas volumes compared to other types of collectors. Electrostatic precipitators can become more economically competitive if several small melting furnaces in one plant are manifolded together to produce a relatively large exhaust gas volume.

Wet Scrubbers

Low energy, wet, centrifugal scrubbers have been applied to controlling emissions from glass-melting furnaces. The collection efficiency for these devices was only about 50 percent.[3] Experimental work is currently being done with high energy venturi scrubbers. This type of scrubber can provide high collection efficiency when operated at a high pressure drop.

The main disadvantages of the Venturi scrubber include the high operating cost due to the high pressure drop across the throat section and the cost of removal and safe disposal of slurries and sludges from the system.

Fabric Filters

Fabric filters have an inherently high collection efficiency, provide for dry product recovery and are relatively simple in their construction and operation.

Disadvantages of fabric filters include a temperature limitation of 550°F and high bag replacement costs. Gas inlet temperatures to the filter must be controlled above the dew point temperature, to prevent the formation of a mud which will blind the filter, and below the temperature limitation of the bag material. Also, at temperatures below the dew point there is rapid chemical attack of the fabric material.

With the pilot bag filters tested to date, the furnace effluent has been cooled below the maximum safe operating temperature for the particular fabric under consideration. The methods used to cool the furnace effluent have included: air dilution, radiation cooling columns, air to gas heat exchangers, and evaporative coolers. The most trouble free method, but one which requires the largest fabric filter, is air dilution. Heat exchangers and radiation ductwork are subject to rapid fouling from dust in the effluent. Evaporative coolers, if not properly designed and installed, can also pose problems with temperature control and condensation.

SPECIFICATIONS AND COSTS

Abatement specifications were written for electrostatic precipitators, wet scrubbers, and fabric filters to remove particulates from the exhaust gas of both a small and a large sode-lime, glass-melting furnace. Since opacity rather than weight rate of particulate matter is the problem requiring control, only one efficiency level was specified for each type of equipment. That level was chosen to correspond to an expected clear stack, although a guarantee of the result could not be specified.

Estimates of capital cost and annual operating costs made by the bidders for each system were averaged and presented in the cost tables and graphs which follow this section.

Specifications for electrostatic precipitators for glass-melting furnaces are shown in Tables 49 and 50. Cost data are presented in Tables 51 and 52 and Figures 32 and 33. Annual operating cost data was supplied by only one of the two bidders.

Bidders for these systems submitted the collector plate areas in addition to their cost data. The areas were averaged and are tabulated below along with calculated drift velocities:

Plant Size	Plate Area ft^2	Calculated Drift Velocity, fps
Small	6400	0.14
Large	15100	0.14

Specifications for wet scrubbers are shown in Tables 53 and 54. Average cost data are presented in Tables 55 and 56 and Figures 34 and 35. Bidders for these systems submitted scrubber pressure drops and L/G ratios in addition to their cost data. Average values are tabulated below:

Plant Size	Scrubber ΔP, in. w.c.	Scrubber L/G, gpm/1000 ACFM
Small	63	8
Large	65	7

Specifications for fabric filter systems for glass-melting furnaces are shown in Tables 57 and 58. Cost data are presented in Tables 59 and 60 and Figures 36 and 37.

Combination shaker, reverse air type fabric filters with an air-to-cloth ratio of about 1½/1 were used for both the small and the large glass melting furnace. One of the two bidders specified a precoat additive upstream of the filter unit. This fact is footnoted on the operating cost table, but is not included in the averaged cost data presented. It should be noted the bidders differed greatly on the cost of many items. The relative difference between highest and lowest was a factor of about two.

TABLE 49

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR GLASS-MELTING FURNACE SPECIFICATION

A single electrostatic precipitator is to remove particulate matter from the exhaust gas of a soda-lime, glass-melting furnace. The furnace is natural gas fired with No. 2 fuel oil standby.

The exhaust gas is to be brought from the furnace exhaust ports to a location 30 feet outside of the furnace enclosure by means of a fan. The precipitator will be at ground level in an area beyond the ductwork which is free of space limitations. The fan will follow the precipitator. The abatement system shall continuously reduce the furnace outlet loading to the levels specified and shall include the following:

1. *Precipitator with a minimum of three independent electrical fields in the direction of gas flow.*
2. *Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.*
3. *A safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected or grounded.*
4. *Automatic voltage control.*
5. *Dust hoppers and conveyors.*
6. *Rapping system which is adjustable in terms of both intensity and rapping period.*
7. *Dust storage with 24-hour capacity.*
8. *Necessary flow controls and dampers.*
9. *A model study for precipitator gas distribution.*
10. *Materials of construction will be ASTM A242 or approved equal.*

TABLE 50

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR GLASS-MELTING FURNACE SPECIFICATION

	Small	Large
Glass Output, ton/day	100	300
Inlet Gas		
Flow, ACFM	25,000	60,000
Temp., °F*	725	725
Flow, SCFM	11,200	26,800
% Moisture (vol)	12	12
Inlet Loading		
Avg. Particle Size, μ	0.25	0.25
Solids Rate, lb/hr	16.9	40.5
Solids Loading, gr/DSCF	.2	.2
Gas Composition, ppm		
F	2.2	1.9
Cl	4.9	4.1
NO_x	340	640
CO	375	40
Outlet Gas		
Outlet Solids Loading		
gr/ACF	0.01	0.01
gr/DSCF	.025	.025
Outlet Solids Rate, lb/hr	2.11	5.05
Efficiency, wt %	88	88

*Can cycle up to 850°F during normal operation.

TABLE 51

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR ELECTROSTATIC PRECIPITATORS
FOR GLASS-MELTING FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			25,000	60,000
°F			725	725
SCFM			11,200	26,800
Moisture Content, Vol. %			12	12
Effluent Contaminant Loading				
gr/ACF			.08	.08
lb/hr			16.9	40.5
Cleaned Gas Flow				
ACFM			25,000	60,000
°F			725	725
SCFM			11,200	26,800
Moisture Content, Vol. %			12	12
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			2.14	5.14
Cleaning Efficiency, %			88	88
(1) Gas Cleaning Device Cost			94,312	152,285
(2) Auxiliaries Cost				
(a) Fan(s)			4,800	6,700
(b) Pump(s)				
(c) Damper(s)			1,309	3,067
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment			3,530	4,120
Model Study			5,066	8,280
(3) Installation Cost			249,796	339,321
(a) Engineering				
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			358,813	513,773

FIGURE 32

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS FOR GLASS-MELTING FURNACE

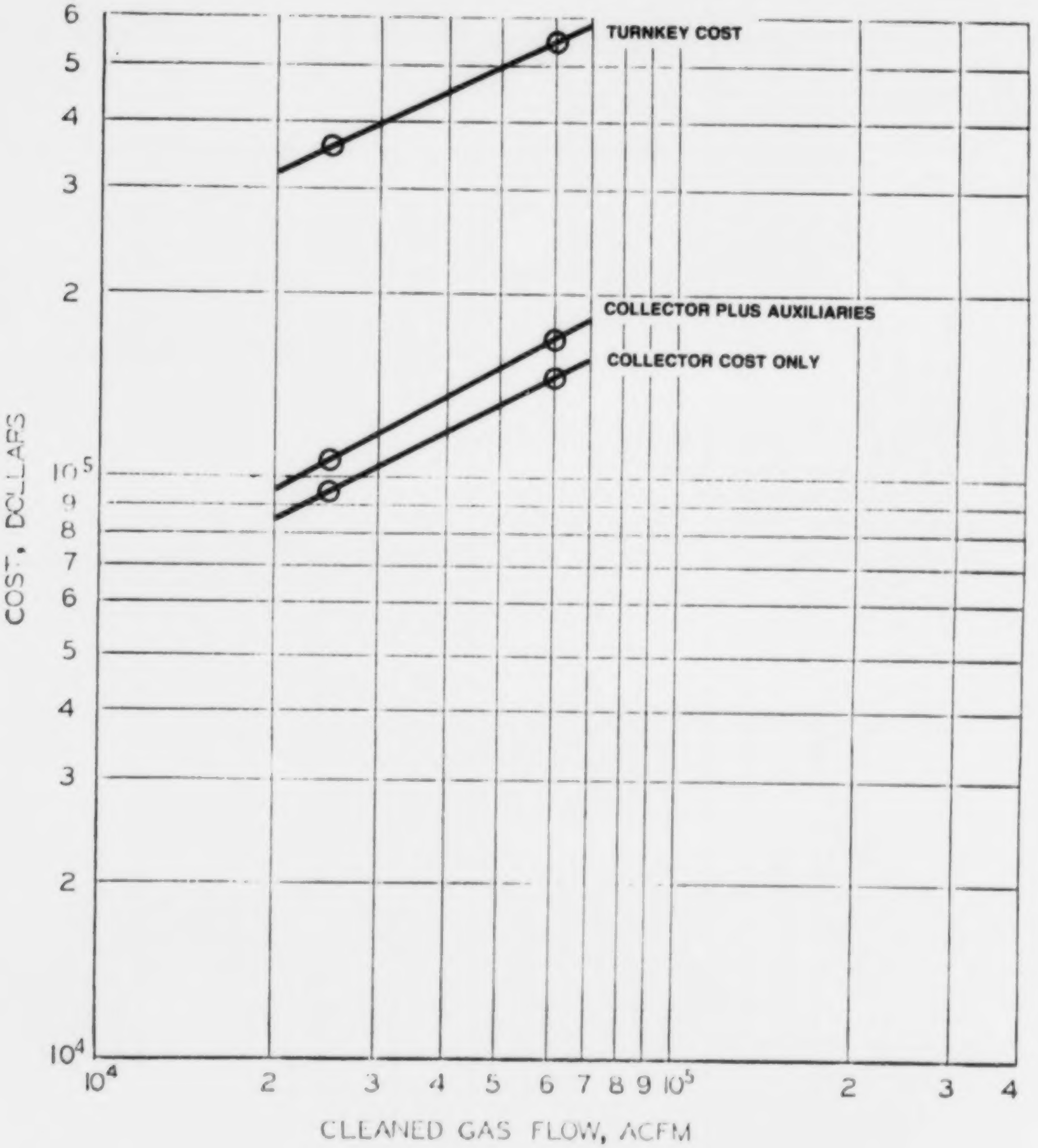


TABLE 52

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS
FOR GLASS-MELTING FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,600					
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor	$6/hr			240	240
Materials				75	125
Total Maintenance				315	365
Replacement Parts				550	550
Total Replacement Parts				550	550
Utilities					
Electric Power	$0.011/kwh			6,467	11,146
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities				6,467	11,146
Total Direct Cost				7,332	12,061
Annualized Capital Charges	16% of Cap			57,410	82,204
Total Annual Cost				64,742	94,265

FIGURE 33

ANNUAL COST OF ELECTROSTATIC PRECIPITATORS FOR GLASS-MELTING FURNACE

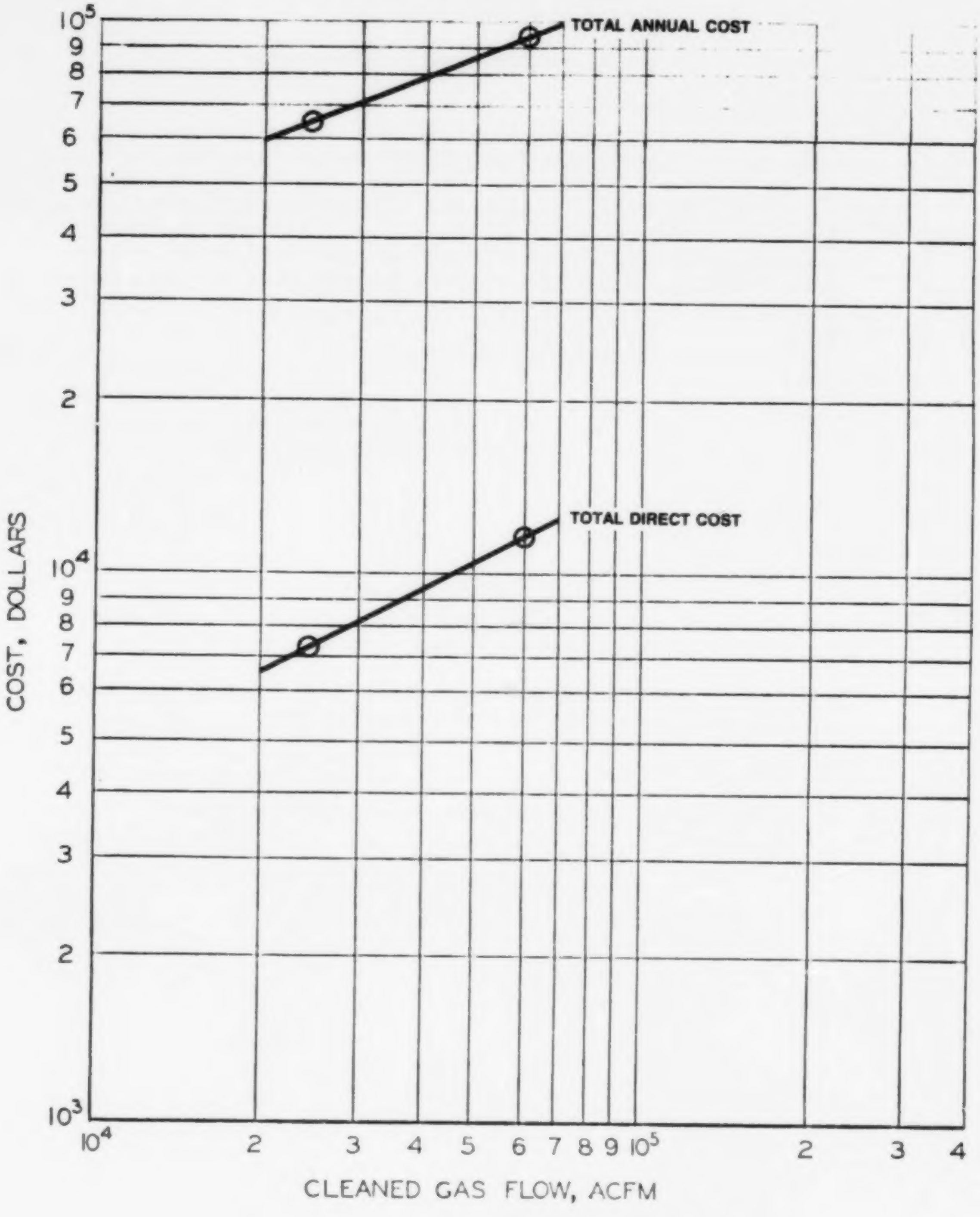


TABLE 53

WET SCRUBBER PROCESS DESCRIPTION

FOR GLASS-MELTING FURNACE SPECIFICATION

A wet scrubber is to remove particulate matter from the exhaust gas of a glass-melting furnace. The furnace is fired with No. 5 fuel oil using 40 percent excess combustion air.

The exhaust gas is to be brought from the furnace exhaust ports to a fan located 30 feet outside of the furnace enclosure. The scrubber will be located before the fan in an area free of space limitation. Fresh make-up water is available and is to be added to the recirculation tank. The scrubber is to operate so as to continuously reduce the furnace outlet loading to the levels specified.

The scrubbing system should include the following:

1. *Venturi scrubber with a cyclonic entrainment separator constructed of carbon steel lined with FRP or rubber with a precooler constructed of Incoloy or brick lined carbon steel. The scrubber internals should be either Incoloy or fiberglass reinforced polyester.*
2. *Recirculation tank and pumps.*
3. *Fifty-foot stack following scrubber.*
4. *Slurry settler, which will handle a portion of the recirculation pump discharge and be capable of producing a reasonably thickened underflow product.*
5. *Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.*
6. *Necessary controls.*
7. *Packing glands flushed with fresh water to prevent binding of the seals.*

TABLE 54

WET SCRUBBER OPERATING CONDITIONS

FOR GLASS-MELTING FURNACE SPECIFICATION

	Small	*Large*
Glass Output, ton/day	100	300
Inlet Gas		
Flow, ACFM	25,000	60,000
Temp., °F	725	725
Flow, SCFM	11,200	26,800
% Moisture (vol)	12	12
Inlet Loading		
Solids Rate, lb/hr	16.9	40.5
Solids Loading, gr/DSCF	.2	.2
Avg. Particle Size, μ	.25	.25
SO_2 Loading, ppm	250	315
SO_3 Loading, ppm	17	15
Fluorine Loading, ppm	2.2	1.9
Chlorine Loading, ppm	4.9	4.1
Nitrogen Oxides, ppm	340	640
Carbon Monoxide, ppm	375	40
Outlet Gas		
Flow, ACFM	15,500	37,200
Temp., °F	152	152
% Moisture (vol)	26	26
Flow DSCFM	9,900	23,800
Outlet Solids Loading		
gr/ACF	0.01	0.01
gr/DSCF	0.02	0.02
Outlet Solid Rate, lb/hr	1.33	3.19
Efficiency, wt %	92	92
*Wet Scrubber ΔP, in. w.c.**	63	65
*Recirculation L/G, GPM/1000 ACFM, out**	8	7

**Supplied by the bidders*

TABLE 55

ESTIMATED CAPITAL COST DATA (COSTS IN DOLLARS) FOR WET SCRUBBERS FOR GLASS-MELTING FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			25,000	60,000
°F			725	725
SCFM			11,200	26,800
Moisture Content, Vol. %			12	12
Effluent Contaminant Loading				
gr/ACF			.08	.08
lb/hr			16.9	40.5
Cleaned Gas Flow				
ACFM			15,500	37,200
°F			152	152
SCFM			13,400	32,200
Moisture Content, Vol. %			26	26
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			1.33	3.19
Cleaning Efficiency, %			92	92
(1) Gas Cleaning Device Cost			13,983	22,418
(2) Auxiliaries Cost				
(a) Fan(s)			37,363	70,455
(b) Pump(s)			1,725	2,698
(c) Damper(s)			175	250
(d) Conditioning, Equipment			17,493	30,493
(e) Dust Disposal Equipment			8,233	8,828
(3) Installation Cost				
(a) Engineering			3,950	3,950
(b) Foundations & Support Ductwork Stack Electrical Piping Insulation Painting Supervision Startup Performance Test Other			62,298	82,518
(4) Total Cost			145,220	221,610

FIGURE 34

CAPITAL COST OF WET SCRUBBERS FOR GLASS-MELTING FURNACE

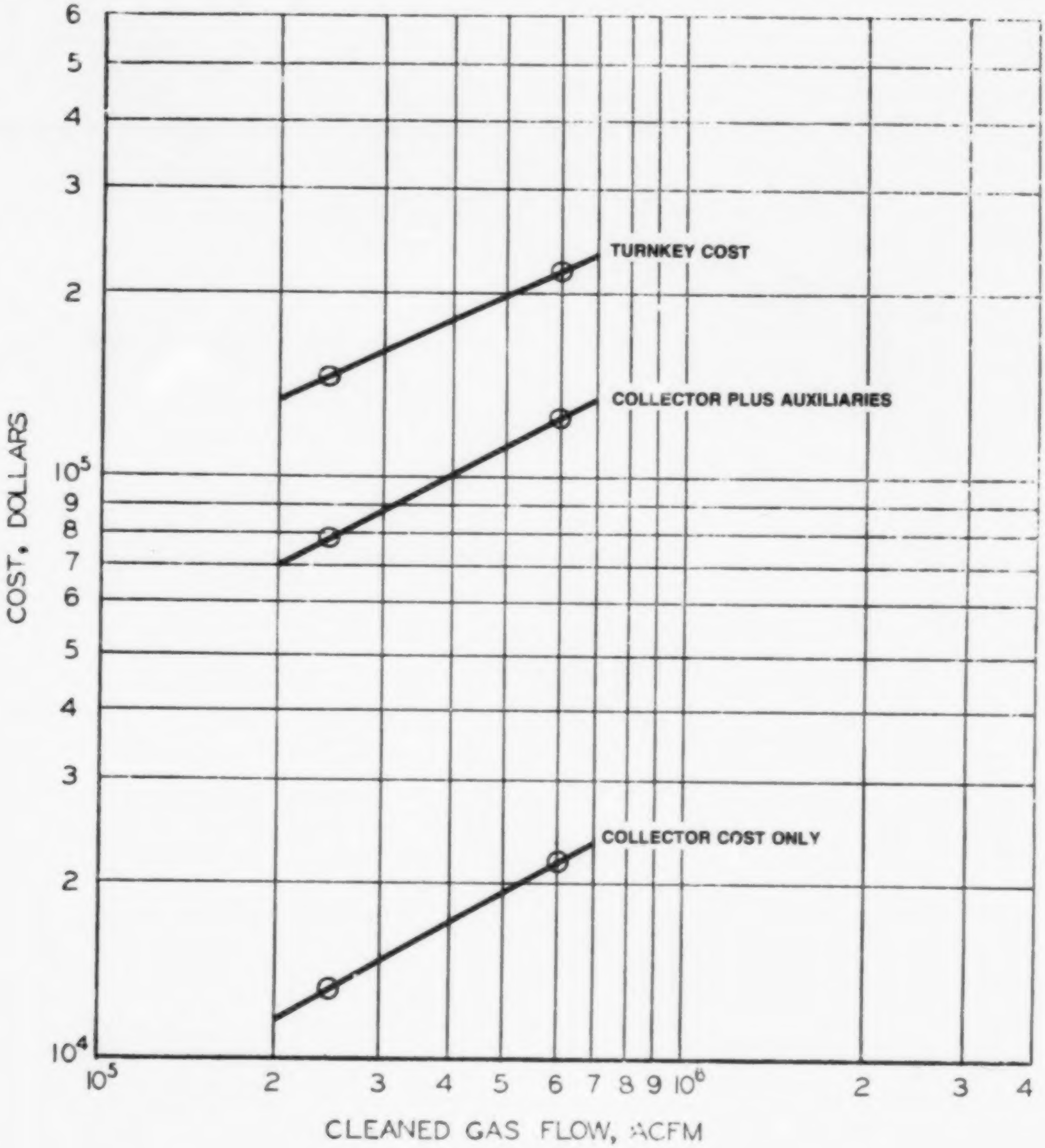


TABLE 56

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS
FOR GLASS MELTING FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,600					
Operating Labor (if any)					
Operator	$6/hr			6,300	6,300
Supervisor	$8/hr			1,600	1,600
Total Operating Labor				7,900	7,900
Maintenance					
Labor	$6/hr			1,950	1,950
Materials				750	875
Total Maintenance				2,700	2,825
Replacement Parts				1,250	2,375
Total Replacement Parts				1,250	2,375
Utilities					
Electric Power	$0.011/kwh			17,683	42,834
Fuel					
Water (Process)	$0.25/MGal			1,506	3,264
Water (Cooling)	$0.05/MGal			353	844
Chemicals, Specify					
Total Utilities				19,542	46,942
Total Direct Cost				31,392	60.042
Annualized Capital Charges	16% of Cap			23,235	35,458
Total Annual Cost				54,627	95,500

FIGURE 35

ANNUAL COST OF WET SCRUBBERS
FOR GLASS-MELTING FURNACE

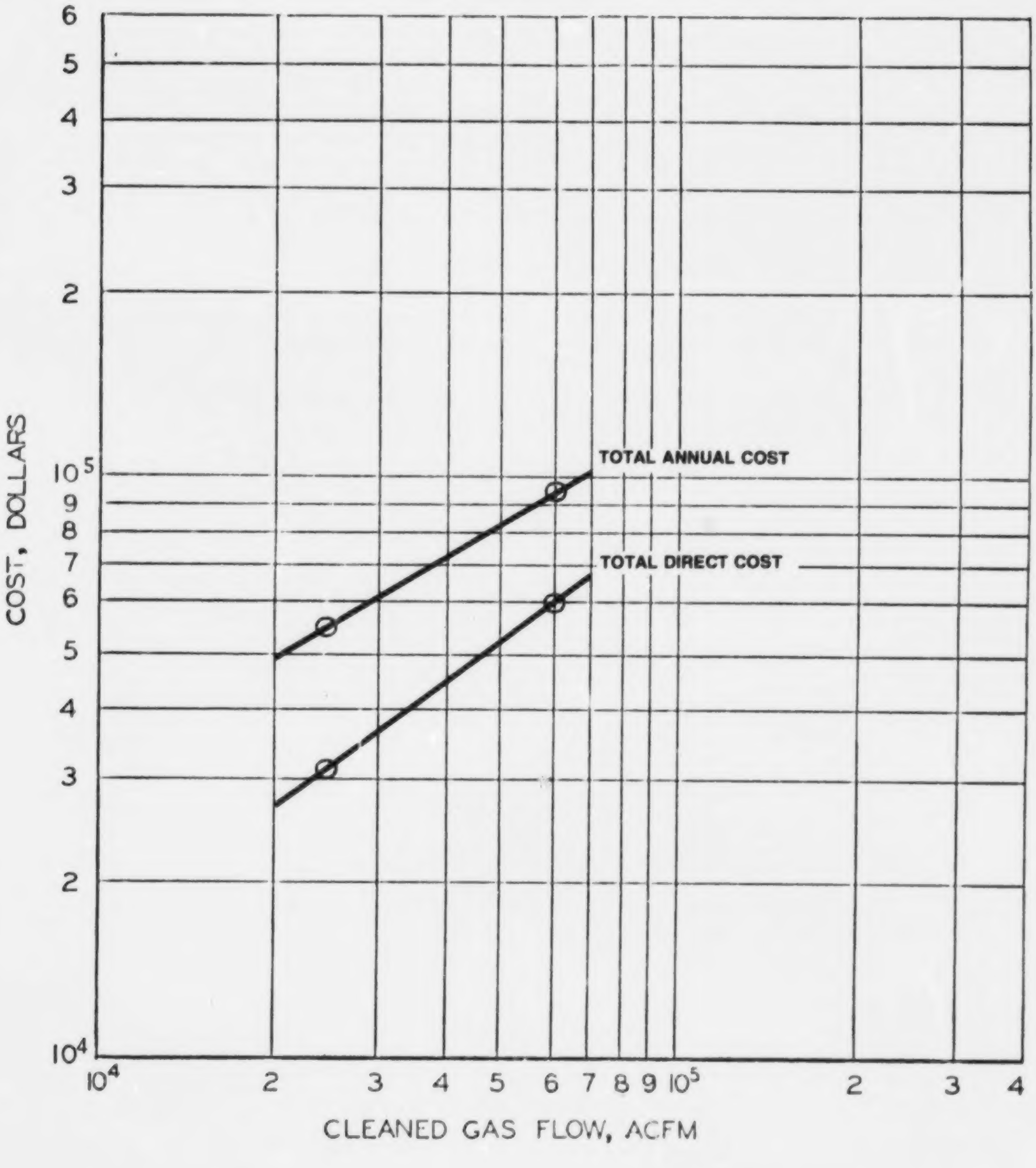


TABLE 57

FABRIC FILTER PROCESS DESCRIPTION

FOR GLASS-MELTING FURNACE SPECIFICATION

A fabric filter is to remove particulate matter from the exhaust gas of a glass-melting furnace. The furnace is fired with No. 5 fuel oil using 40 percent excess combustion air.

The exhaust gas is to be brought from the furnace exhaust ports to a location 30 feet outside of the furnace enclosure by means of a fan. The fabric filter will be at ground level in an area beyond the ductwork which is free of space limitations. The fan will precede the fabric filter. The abatement system shall continuously reduce the furnace outlet loading to the levels specified and shall include the following:

1. *Compartmented fabric filter operating with positive pressure.*
2. *Fan sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.*
3. *A surface cooler to lower the temperature of the gas going to the fabric filter to ≤425°F during normal operation.*
4. *Compartmented design of the fabric filter which permits shutdown of one section for maintenance.*
5. *Bags with a temperature rating of ≥500°F.*
6. *A high temperature by-pass around the fabric filter for use during operational upsets.*
7. *Dust hoppers and conveyors.*
8. *Materials of construction capable of handling furnace exhaust gas containing the following:*

Component	*Average Concentration, ppm*
SO_2	250
SO_3	17
F	2.2
Cl	4.9
NO_x	340

TABLE 56

FABRIC FILTER OPERATING CONDITIONS

FOR GLASS-MELTING FURNACE SPECIFICATION

	Small	*Large*
Glass Output, ton/day	*100*	*300*
Gas to Surface Cooler		
Flow, ACFM	*25,000*	*60,000*
*Temp., °F**	*725*	*725*
Flow, SCFM	*11,200*	*26,800*
% Moisture (vol)	*12*	*12*
Gas to Collector		
Flow, ACFM	*18,700*	*44,750*
*Temp., °F**	*425*	*425*
Flow, SCFM	*11,200*	*26,800*
% Moisture (vol)	*12*	*12*
Inlet Loading		
Solids Rate, lb/hr	*16.9*	*40.5*
Solids Loading, gr/DSCF	*.2*	*.2*
Avg. Particle Size, μm	*0.25*	*0.25*
Outlet Loading		
Solids Rate, lb/hr	*1.6*	*3.84*
Solids Loading, gr/ACF	*0.01*	*0.01*
Solids Loading, gr/DSCF	*.019*	*.019*
Efficiency, wt %	*91*	*91*
*Air to Cloth Ratio, ACFM/ft^{2}***	*1.5*	*1.5*

**Can cycle up to 850°F during normal operation*
***Supplied by the bidders*

TABLE 59

ESTIMATED CAPITAL COST DATA (COSTS IN DOLLARS) FOR FABRIC FILTERS FOR GLASS-MELTING FURNACE

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			25,000	60,000
°F			725	725
SCFM			11,200	26,800
Moisture Content, Vol. %			12	12
Effluent Contaminant Loading				
gr/ACF			.10	.10
lb/hr			16.9	40.5
Cleaned Gas Flow				
ACFM			18,700	44,750
°F			425	425
SCFM			11,200	26,800
Moisture Content, Vol. %			12	12
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			1.6	3.84
Cleaning Efficiency, %			91	91
(1) Gas Cleaning Device Cost			78,871	147,338
(2) Auxiliaries Cost				
(a) Fan(s)			7,673	15,730
(b) Pump(s)				
(c) Damper(s)			8,823	11,744
(d) Conditioning, Equipment			21,871	47,432
(e) Dust Disposal Equipment			3,619	4,563
(3) Installation Cost				
(a) Engineering			17,838	22,450
(b) Foundations & Support			10,000	17,250
Ductwork			8,229	12,696
Stack			2,090	3,120
Electrical			7,500	10,000
Piping			500	850
Insulation			27,375	45,638
Painting			*	*
Supervision			7,830	11,515
Startup			1,060	1,560
Performance Test			3,000	4,000
Other			57,911	112,983
(4) Total Cost			264,190	468,949

*Included in (1) above

FIGURE 36

CAPITAL COST OF FABRIC FILTERS FOR GLASS-MELTING FURNACE

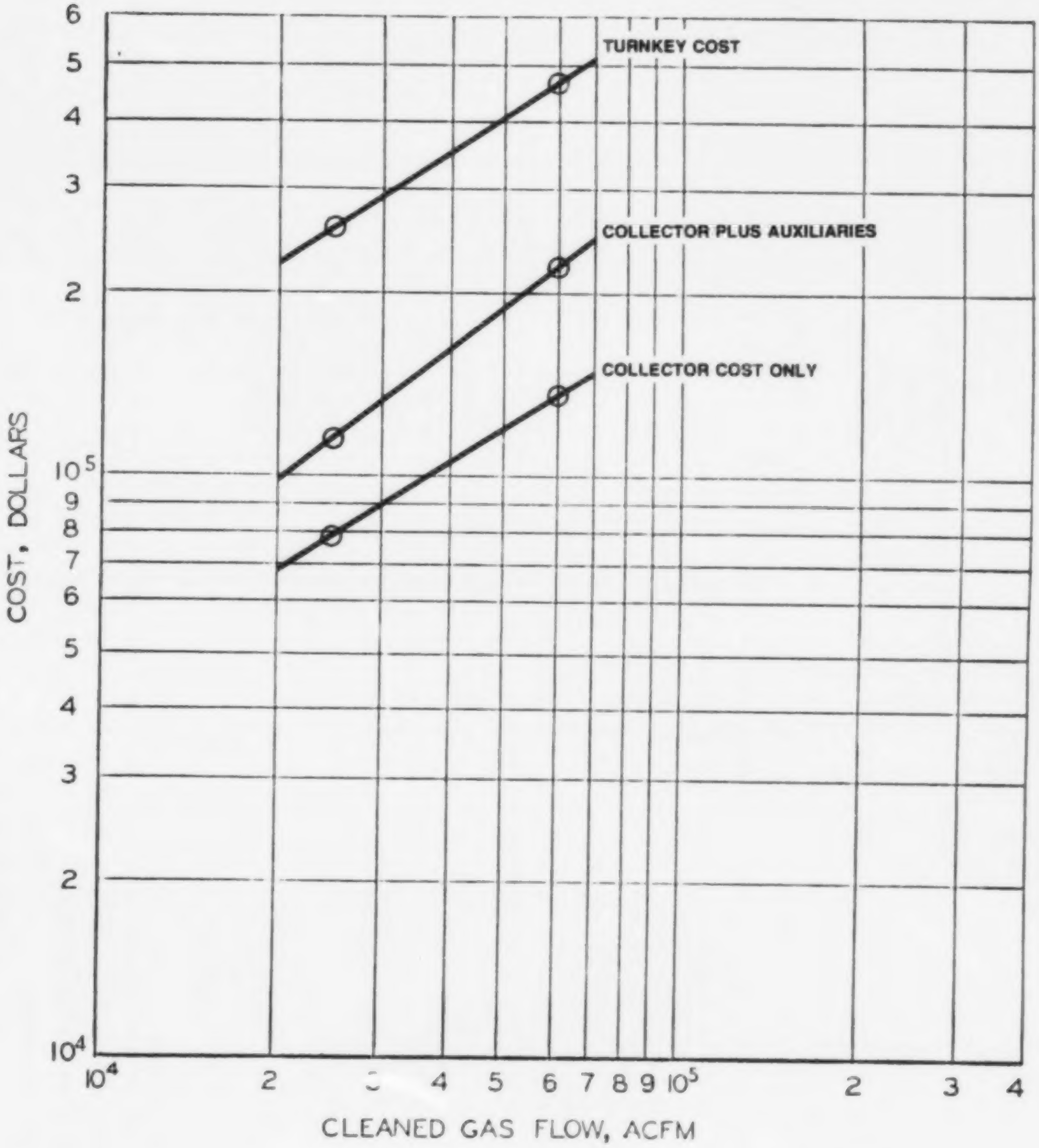


TABLE 60

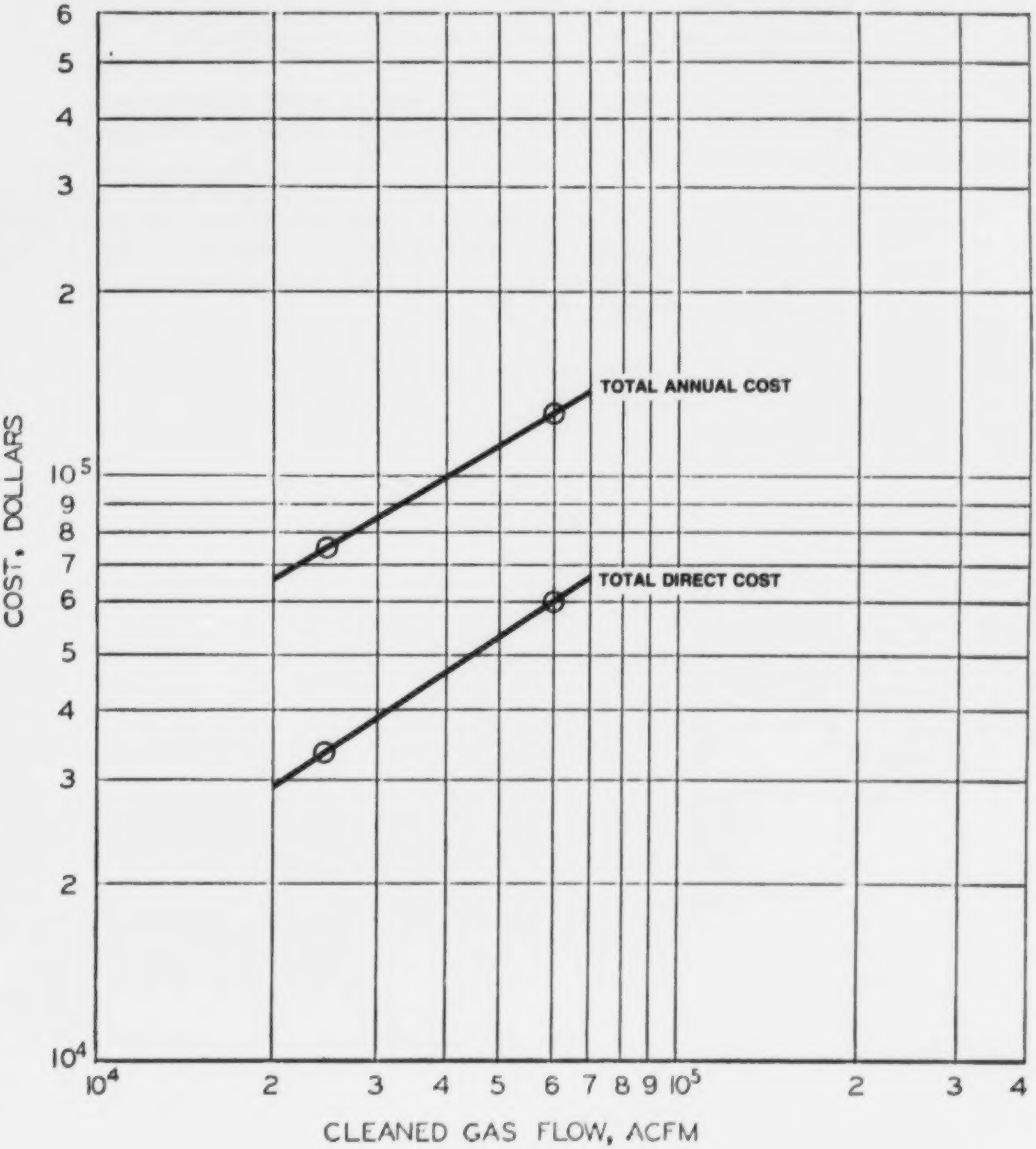
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS
FOR GLASS-MELTING FURNACE

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,600					
Operating Labor (if any)					
Operator	$6/hr.			2,681	3,984
Supervisor	$8/hr.			835	922
Total Operating Labor				3,516	4,906
Maintenance					
Labor	$6/hr.			1,679	2,674
Materials & Replacement Parts				11,773	22,108
Total				13,452	24,782
Utilities					
Electric Power	$0.011/kwh			16,763	30,739
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify *					
Total Utilities				16,763	30,739
Total Direct Cost				33,731	60,427
Annualized Capital Charges	16% of Cap			42,270	75,032
Total Annual Cost				76,001	135,459

*One bidder recommended the use of a precoat at a cost of $2,000 and $4,200 for the small and large fabric filters.

FIGURE 37

ANNUAL COST OF FABRIC FILTERS FOR GLASS-MELTING FURNACE



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5. CRUSHED STONE AND AGGREGATE INDUSTRY

The art of obtaining stone from the earth's crust is quarrying. Quarrying is referred to as open-pit mining when applied to ore bearing stone, and strip mining when applied to coal mining.

Rocks that are quarried for commercial use fall into three general classifications: igneous, sedimentary, and metamorphic. Igneous rock is that formed by volcanic action or great heat; sedimentary rock is that formed by the deposit of sediment; and metamorphic rock is that formed from igneous or sedimentary rock which has undergone a change in structure due to intense pressure, heat, or chemical reaction.

Two main products of the quarrying industries are dimension stone and crushed and broken stone. The term dimension stone is applied to blocks or slabs of natural stone that are cut to definite shapes and sizes. Crushed and broken stone generally consists of irregular fragments produced by passing the stone through crushers.

In quarrying dimension stone, blocks must be removed with care to preserve their strength and weather resistance. The principal uses of dimension stone are exterior and interior building construction. Granites and marbles are also used extensively for memorials ranging from headstones to elaborate mausoleums. Slate is used for roofing, stair treads, blackboards, and many other applications. Sandstones are used as building stone and for abrasive wheels.

Although the use of stone in fragmentary form is a comparatively recent development (the first crushing machine was patented in 1830), the crushed stone industry has far outstripped the dimension stone industry in tonnage. The chief varieties of rock used are limestone, sandstone, granite, and traprock (which includes diabase, basalt and gabbro). Since the stone is used in small fragments, explosives are used for shattering.

The first operation in preparation for blasting is to drill a series of deep holes in rows. A churn drill or well drill is often used to sink holes 6 inches or more in diameter and 50 or more feet deep.[2] In large quarries 40 or more holes may be drilled for a single blast. The size of the charge in each hole is determined by the toughness of the rock. The charges may be fired in progression or simultaneously. A single blast may throw down 20,000 or more tons of broken stone.

The broken stone is loaded by large capacity power shovels and then transported to primary crushers where it is reduced to an average size of about six inches. The desired fines are separated by scalping and screening, and the larger sizes are further reduced by smaller secondary and tertiary crushers.

Crushed stone is used chiefly for road building, cement manufacturing, for agricultural purposes, in metallurgical fluxes, concrete aggregate and railroad track ballast. Limestone has special uses in many chemical applications.

PROCESS DESCRIPTION

Quarrying, or open-pit mining, is a common method used to extract consolidated ore or rock deposits that are located at or near the earth's surface. Open-pit mining consists of the following steps:

1. Site preparation — constructing access roads, designating dump sites, and clearing vegetation and other obstructions.
2. Removal and disposal of overburden.
3. Excavation and collection of the deposit.
4. Transportation of the mined resource for processing.

The drilling of shotholes and exploratory boreholes in hard rock is an essential part of all quarrying operations. There has been continual progress in the development of more efficient rock drills and drilling accessories. Two main types of wet percussive drill have emerged; the internal or axial water feed machines, and the external or flush-head machines. Great advances have also been made in the development and manufacture of various types of dust extraction and filtration devices, thus enabling the drilling to be performed without the aid of water.

In hard-rock mining, special arrangements have to be made to protect workers against dust and fumes. Holes are drilled, charged, and fired according to a prearranged program. The actual firing of explosives is done near the end of the shift when nearly all the workers are out of the mine.

After blasting, various types of mechanical equipment are used for picking up the spoil and loading it into cars or onto a conveyor. Scraper loaders that draw the spoil up a ramp into cars are also used. A further development of this principle involves the use of a power shovel in conjunction with a scraper that is mounted on a train of cars and distributes the spoil throughout the length of the train. Although sometimes sent to large capacity bins first, the rock in most cases is delivered directly to the primary crusher plant by rail, rope haulage, conveyor belt, or diesel truck. Commonly, broken stone is loaded into large-haul (20 to 75-ton capacity) trucks by front-end loaders or shovels. The rock is then hauled via unimproved roads to the processing plant or primary crusher truck dump. The usual crushing plant, situated either at the mine or at the mill, consists of jaw or gyratory crushers as the primary stage, followed by gyratory, cone, or impact crushers for the final stages.

The processing consists of screening out the usable sizes and crushing the oversize rock into smaller usable size ranges. A simplified flow diagram for a typical plant is shown in Figure 38. Incoming material is routed through a primary crusher which crushes rocks larger than six inches. The product from this crusher is screened for further processing. The undersize goes to a final screening plant and the oversize to the secondary crushing plant. The secondary crushers are of the gyratory, cone, or impact type. In a few large plants, two or three primary crushers are used in parallel, followed by any number of secondary crushers which may or may not be in parallel.

Jaw crushers have two crushing plates (jaws), usually with one pivoted, and moving alternately toward or away from each other. Maximum size feed is about 80 inches in diameter and usual reduction ratios (ratio of feed size to product size) are about 5:1 to 8:1.

Gyratory crushers have an outer stationary face which is a vertical, truncated conical shell (concave) with the smaller diameter at the bottom. The inner movable face is a similar shell (crushing head) mounted on a spindle, with the smaller diameter at the top. The movement of the spindle causes the crushing head to gyrate, alternately moving toward and away from all the points on the circumference of the concave. Maximum size feed is about 80 inches and usual reduction ratios are about 5:1 to 8:1.

A cone crusher is a modification of the gyratory crusher, and is specially adapted to fine crushing. Maximum feed size for cone crushers is about 17 inches. Average reduction ratios are about 6:1 to 8:1. Feed size is usually restricted to about 80% of the feed opening.

Impact crushers such as the hammermill ordinarily consist of a frame or housing, a central rotating shaft on which the hammers are mounted, and a set of grates which are circumferentially arranged in the lower section of the housing. Rotational kinetic energy is transmitted from the hammers to the rock, and the rock is shattered into smaller fragments. By increasing the number of these shattering stages, size reductions of 20:1 may be realized in open circuit for 3 to 6 inch diameter rock.

NATURE OF THE GASEOUS DISCHARGE

Particulate matter produced during open-pit mining operations is usually

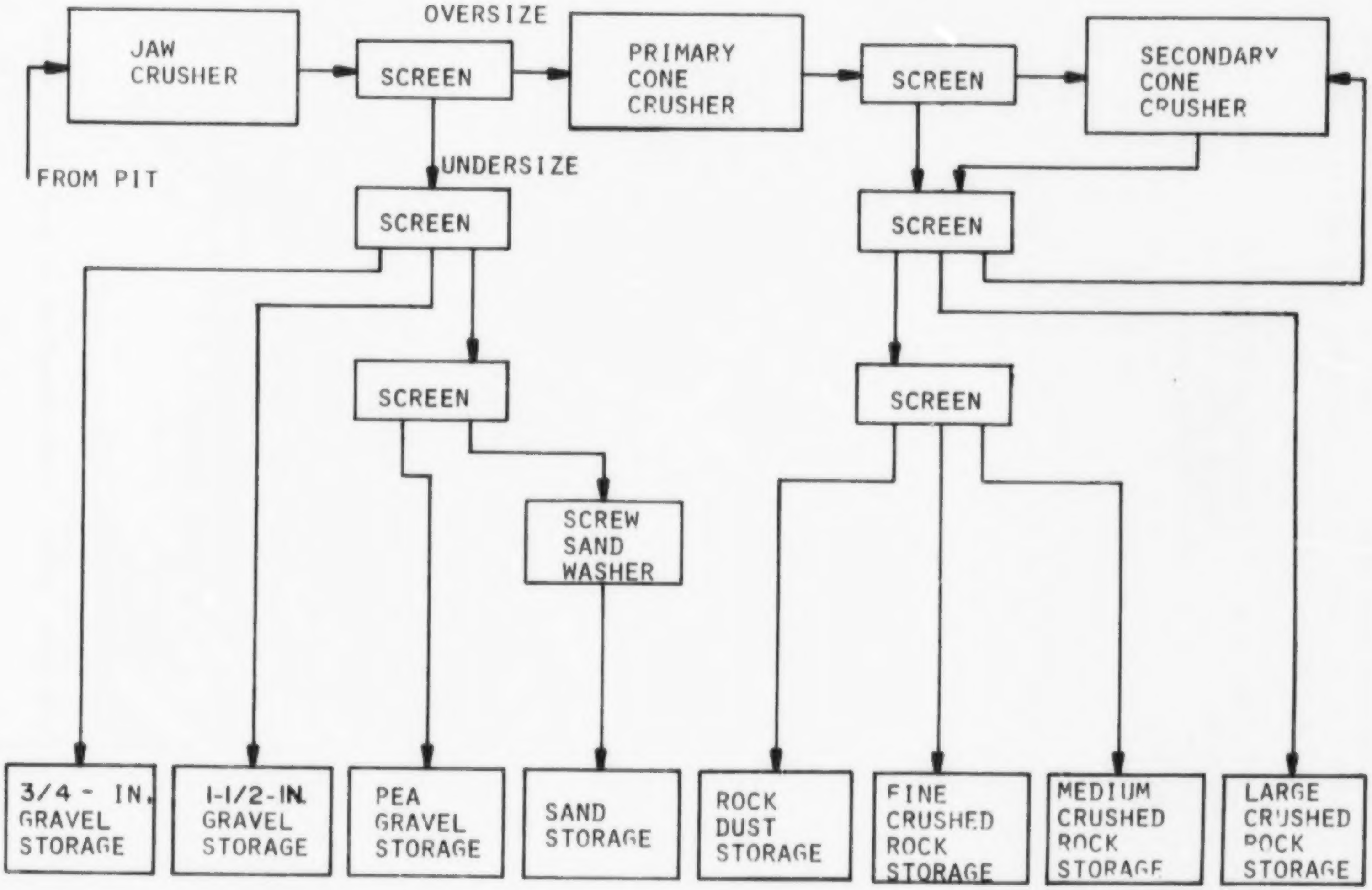

JAW CRUSHER
FROM PIT
SCREEN
OVERSIZE
UNDERSIZE
PRIMARY CONE CRUSHER
SCREEN
SECONDARY CONE CRUSHER
SCREEN
SCREEN
SCREEN
SCREEN
SCREW SAND WASHER
3/4 - IN. GRAVEL STORAGE
1-1/2-IN. GRAVEL STORAGE
PEA GRAVEL STORAGE
SAND STORAGE
ROCK DUST STORAGE
FINE CRUSHED ROCK STORAGE
MEDIUM CRUSHED ROCK STORAGE
LARGE CRUSHED ROCK STORAGE

FIGURE 38

SIMPLIFIED FLOW DIAGRAM OF A TYPICAL ROCK GRAVEL PLANT[1]

convected or permeated directly to the atmosphere, rather than being captured by a local exhaust ventilation system. In other words, the emissions are fugitive in nature. Since many open-pit mining operations have an indefinite operating life, the installation of a fixed dust collecting system is economically impractical. Therefore, fugitive dusts should be controlled at the point of operation. Drilling, blasting, rock handling operations, and wind erosion are responsible for most of the particulate matter emissions produced during open-pit mining.[3]

Water can be used in most open-pit mining operations to control the generated dusts. In all cases, the use of rotary or percussive drills of various types will lead to the production of some amounts of fine respirable dust. The provision of an efficient water feed or some other method of dust control is essential. It is also essential that all surfaces in the immediate vicinity be watered down before drilling begins. This method is only effective at temperatures above the freezing point of water.

The oldest method of combating dust from shotfiring is to fill a stretch of road with a water fog. This fog assists in precipitating the dust and fumes produced. It is delivered towards the face of the rock to be shotfired through an air-water nozzle.

All scraping, loading and conveying operations are potential sources of fugitive dust emissions. Dust production during scraping and loading operations is best controlled by thorough and systematic watering when temperatures are above the freezing point of water. The loose material should be watered before scraping or loading begins and from time to time during operations so that exposure of dry rock is avoided.

The transport of material from one piece of equipment to another is usually accomplished by bucket elevators or, more frequently, by belt conveyors. A point at which material enters or leaves a conveyor belt is called a conveyor transfer point.

Dust emission in the rock crushing plant usually begins at the primary crusher and continues with the conveyor transfer points and the succeeding crushers. As the rock becomes smaller in size, dust emissions become greater. Dust emissions exist at all conveyor transfer points, dumps, crushers and screens.

The nature and the quantity of emissions depend upon the type of rock, the moisture content of the rock, and the kind of processing equipment that is used. Table 61 summarizes the unit operations encountered in most rock and mineral production operations. It also lists air pollution control techniques applicable to these unit operations.

TABLE 61

ROCK AND MINERAL PRODUCTION UNIT OPERATIONS[3]

	OPERATION	CONTROL TECHNIQUES*
A.	Mining	
	Open pit and quarry roads	Paving; periodic oiling, watering, $CaCl_2$ cover, and/or cleaning; covering trucks to prevent spillage.
	Blasting	Controlling size of blast, using water sprays immediately after blasting and blasting only when wind direction and other meterological conditions are such that "neighborhood dusting" will not occur. Using "blasting mats".
	Drilling	Wet drilling (not fully accepted) or local exhaust ventilation.
B.	Transportation and storage	
	Conveyor belts	Enclosure and local exhaust ventilation.
	Elevators	Enclosure and local exhaust ventilation.
	Discharge chutes	Telescoping chutes or adjustable chute heads to permit discharge point to be close to surface of pile. Spray or local exhaust ventilation at discharge point.
	Storage piles	Enclosure (silos, bins, etc.).
C.	Size reduction	
	Crushing & grinding	Enclosure and local exhaust ventilation. Wet sprays and/or exhaust hoods at crusher inlet and outlet.
D.	Concentration, classification & mixing	Enclosures and local exhaust ventilation. Where possible employ wet sprays.

*Watering is not effective in keeping down dust at temperatures below freezing.

POLLUTION CONTROL CONSIDERATIONS

Dust emissions from crushed stone and aggregate production operations originate from three main sources:

1. Fugitive emissions from drilling, blasting, and rock handling operations.
2. All elevator and belt conveyor transfer points, all crusher discharge points and all screens.
3. Plant roads and stockpiles.

The fugitive emissions should be controlled by preventing their occurrence. When temperatures are above freezing this is accomplished, as discussed in the previous section, through the liberal use of water at the point at which the emissions might otherwise be generated.

The points that require hooding and ventilation should be enclosed as completely as possible and plant design should incorporate minimum material falls. A minimum indraft velocity of 200 fpm should be maintained through all open areas. The following rules are also a guide to the amount of ventilation air required.[1]

1. Conveyor transfer points require between 350 and 500 cfm per foot of belt width for belt speeds of less than 200 fpm and 500 to 600 cfm per ft of belt width for belt speeds between 200 and 400 fpm.
2. Bucket elevators require a tight casing with a ventilation rate of 100 cfm per square foot of casing cross section.
3. Vibrating screens require a minimum of 50 cfm per square foot of screen area, with no increase for multiple decks.

The most commonly used type of dust collection device is the fabric filter. In large facilities that maintain continuous operation, compartmented fabric filters capable of cleaning themselves during operation are required. Smaller facilities can use equipment that must be cleaned while shut down. Cotton sateen or dacron polyester bags are commonly used. The dust is collected dry by the fabric filter and can be a saleable product.

Medium and high energy wet scrubbers have also been applied to control dust emissions in this industry. They are often preceded by a dry mechanical collector. The dust is collected in the scrubber as a slurry, is not saleable, and must be disposed of in other ways.

SPECIFICATIONS AND COSTS

Cost data were obtained for emission control systems for two typical types of sources: rock crushers and conveyor transfer points. Both fabric filter and high energy wet scrubber systems were studied for each type of source.

Rock Crushers

Specifications were written for fabric filters and wet scrubbers to control the combined emissions from secondary and tertiary rock crushers. Specifications were written for each of two model plant sizes. In the case of wet scrubbers, two collection efficiency levels were specified for each plant size. Only one efficiency level was specified for the fabric filters. Volumetric flow rates and other parameters that were representative of plants in the industry were selected on the basis of information compiled by the National Crushed Stone Association.

The specifications for wet scrubbers are shown in Tables 62 and 63. Averaged capital and operating cost data for the systems bid from these specifications are presented in Tables 64 and 65 and in Figures 39, 40, 41, and 42. In addition to the cost data, bidders reported scrubber pressure drops and L/G ratios for the systems they bid. Averaged values for these data are tabulated below.

Plant Size	Flow Rate ACFM	Collection Efficiency	Scrubber ΔP in w.c.	Scrubber L/G gpm/1000 ACFM (outlet)
Small	20,000	Medium	7	9
Small	20,000	High	17	13
Large	70,000	Medium	9	9
Large	70,000	High	16	13

The specifications for fabric filters are shown in Tables 70 and 71. Averaged capital and operating cost data for control systems bid from these specifications are presented in Tables 72 and 73 and in Figures 47 and 48. In addition to cost data, the bidders reported the air-to-cloth ratio for their unit. These data were averaged and are tabulated below:

Plant Size	Flow Rate ACFM	Filter Air-to-Cloth Ratio, ACFM/ft²
Small	20,000	4.5
Large	70,000	4.5

Conveyor Transfer Points

Specifications were also written for fabric filters and wet scrubbers applied to typical conveyor transfer points. A factor of 500 ACFM per linear foot of belt width was utilized to determine volumetric flow rates for the transfer points in the model plants. Hoods from 54", 30" and 36"-wide belt conveyors were ducted together for the small plant. The large plant had eight transfer points which included four 54" and four 36"-wide conveyor belts. Wet scrubber specifications for the transfer point applications are shown in Tables 66 and 67. Average capital and operating cost data are presented in Tables 68 and 69 and in Figures 43, 44, 45 and 46. In addition to cost data, bidders reported the scrubber pressure drop and L/G ratio which pertains to their bid. Averaged values are tabulated below:

Flow Rate, ACFM	Collection Efficiency	Scrubber ΔP in w.c.	Scrubber L/G gpm/1000 ACFM (outlet)
5000	Medium	7	8
5000	High	12	9
15000	Medium	7	9
15000	High	12	9

The data for the high efficiency cases indicate that less severe conditions are required, at comparable collection efficiency, for conveyor transfer point applications than for crusher applications.

The specifications for fabric filters are shown in Tables 74 and 75. Averaged capital and operating cost data for the systems bid from these specifications are presented in Tables 76 and 77 and in Figures 49 and 50. Bidders reported the air-to-cloth ratios for the fabric filters in addition to their cost data. Average values are tabulated below:

Transfer Point Flow Rate ACFM	Air-to-Cloth Ratio ACFM/ft^2
5000	5.0
15000	5.2

These values average about 10% higher than the corresponding values for the units quoted for crusher applications.

TABLE 62

WET SCRUBBER PROCESS DESCRIPTION

FOR SECONDARY AND TERTIARY ROCK CRUSHER SPECIFICATION

A scrubber is to remove the rock dust exhausted from the secondary and tertiary crushers of a rock crushing plant. Hoods will be supplied by the bidder. The exhaust points will be ducted together and brought to the inlet of the scrubber. The amount of inlet ductwork required will be 100 ft.

The scrubber will be located in an open area. Fresh make-up water and sufficient power are available. The scrubbing system will consist of the following:

1. *Venturi scrubber with a cyclonic entrainment separator.*
2. *Recirculation tank and pumps.*
3. *Slurry settler, which will handle a portion of the recirculation pump discharge and be capable of producing a reasonably thickened underflow product while returning water treated to minimize solids content. Slurry withdrawal should be set to maintain 10% (by weight) solids when operating at design capacity.*
4. *Two filters (one standby) to dewater the slurry product, capable of producing a cake with a minimum 65% (by weight) solids.*
5. *Fan sized with at least 20% excess capacity when operating at the design pressure drop and not more than 90% of the maximum recommended operating speed.*
6. *Necessary controls.*
7. *Carbon steel construction.*

TABLE 63

WET SCRUBBER OPERATING CONDITIONS

FOR SECONDARY AND TERTIARY ROCK CRUSHER SPECIFICATION

Two sizes of wet scrubbers are to be quoted for each of two efficiency levels. Vendor's quotations should consist of four separate and independent quotations.

	Small	*Large*
Process Wt., ton/hr	*300*	*1,200*
No. of Crushers Hooded Together	*2*	*2*
Inlet Gas		
Flow, ACFM	*20,000*	*70,000*
Temp., °F	*80*	*80*
Flow, SCFM	*19,600*	*68,700*
Solids Loading		
gr/ACF	*5.25*	*6.00*
gr/DSCF	*5.70*	*6.50*
lb/hr	*900*	*3,600*
Medium Efficiency		
Flow, ACFM	*20,000*	*70,000*
Scrubber, ΔP, in. w.c.	*	*
Solids Loading		
gr/ACF	*0.23*	*0.076*
gr/DSCF	*0.25*	*0.076*
lb/hr	*40*	*40*
Collector Efficiency, wt %	*95.6*	*98.9*
High Efficiency		
Flow, ACFM	*20,000*	*70,000*
Scrubber, ΔP, in. w.c.	*	*
Solids Loading		
gr/ACF	*0.01*	*0.01*
gr/DSCF	*0.011*	*0.011*
lb/hr	*1.7*	*6.0*
Collector Efficiency, wt %	*99.8*	*99.8*

**To be supplied by vendor as a part of his quotation. Vendor should also supply required liquid circulation rate.*

TABLE 64

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR SECONDARY AND TERTIARY ROCK CRUSHERS

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	20,000	70,000	20,000	70,000
°F	80	80	80	80
SCFM	19,600	68,700	19,600	68,700
Moisture Content, Vol. %				
Effluent Contaminant Loading				
gr/ACF	5.25	6.00	5.25	6.00
lb/hr	900	2,600	900	3,600
Cleaned Gas Flow				
ACFM	20,000	70,000	20,000	70,000
°F	80	80	80	80
SCFM	19,600	68,700	19,600	68,700
Moisture Content, Vol. %	2	2	2	2
Cleaned Gas Contaminant Loading				
gr/ACF	.23	.07	.01	.01
lb/hr	40	40	1.7	6.0
Cleaning Efficiency, %	95.6	98.9	99.8	99.8
(1) Gas Cleaning Device Cost	14,491	34,148	14,156	34,556
(2) Auxiliaries Cost				
(a) Fan(s)	5,522	18,092	14,253	28,290
(b) Pump(s)	2,699	5,175	5,598	5,924
(c) Damper(s)	2,400	6,932	5,200	6,932
(d) Conditioning, Equipment	3,113	4,036	4,016	5,084
(e) Dust Disposal Equipment	9,887	18,220	9,887	18,220
(3) Installation Cost				
(a) Engineering	81,116	127,650	86,807	138,566
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test	2,333	2,333	2,333	2,333
Other				
(4) Total Cost	121,561	216,586	142,250	239,905

TABLE 65

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS
FOR SECONDARY AND TERTIARY ROCK CRUSHERS

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,500					
Operating Labor (if any)					
Operator	$6/hr.				
Supervisor	$8/hr.	6,086	7,027	6,086	7,027
Total Operating Labor		6,086	7,027	6,086	7,027
Maintenance					
Labor	$6/hr.	4,540	5,875	4,540	5,875
Materials		850	1,267	1,150	1,600
Total Maintenance		5,390	7,142	5,690	7,475
Replacement Parts		3,992	5,733	5,367	6,400
Total Replacement Parts		3,992	5,733	5,367	6,400
Utilities					
Electric Power	$0.011/kwh	6,409	31,014	10,911	39,180
Fuel					
Water (Process)	$0.25/MGal	603	2,157	606	2,159
Water (Cooling)					
Chemicals, Specify					
Total Utilities		7,012	33,171	11,517	41,339
Total Direct Cost		22,480	53,073	28,660	62,241
Annualized Capital Charges	16% of Cap	19,450	34,654	22,760	38,385
Total Annual Cost		41,930	87,727	51,420	100,626

FIGURE 39

CAPITAL COST OF WET SCRUBBERS FOR SECONDARY AND TERTIARY ROCK CRUSHERS
(Medium Efficiency)

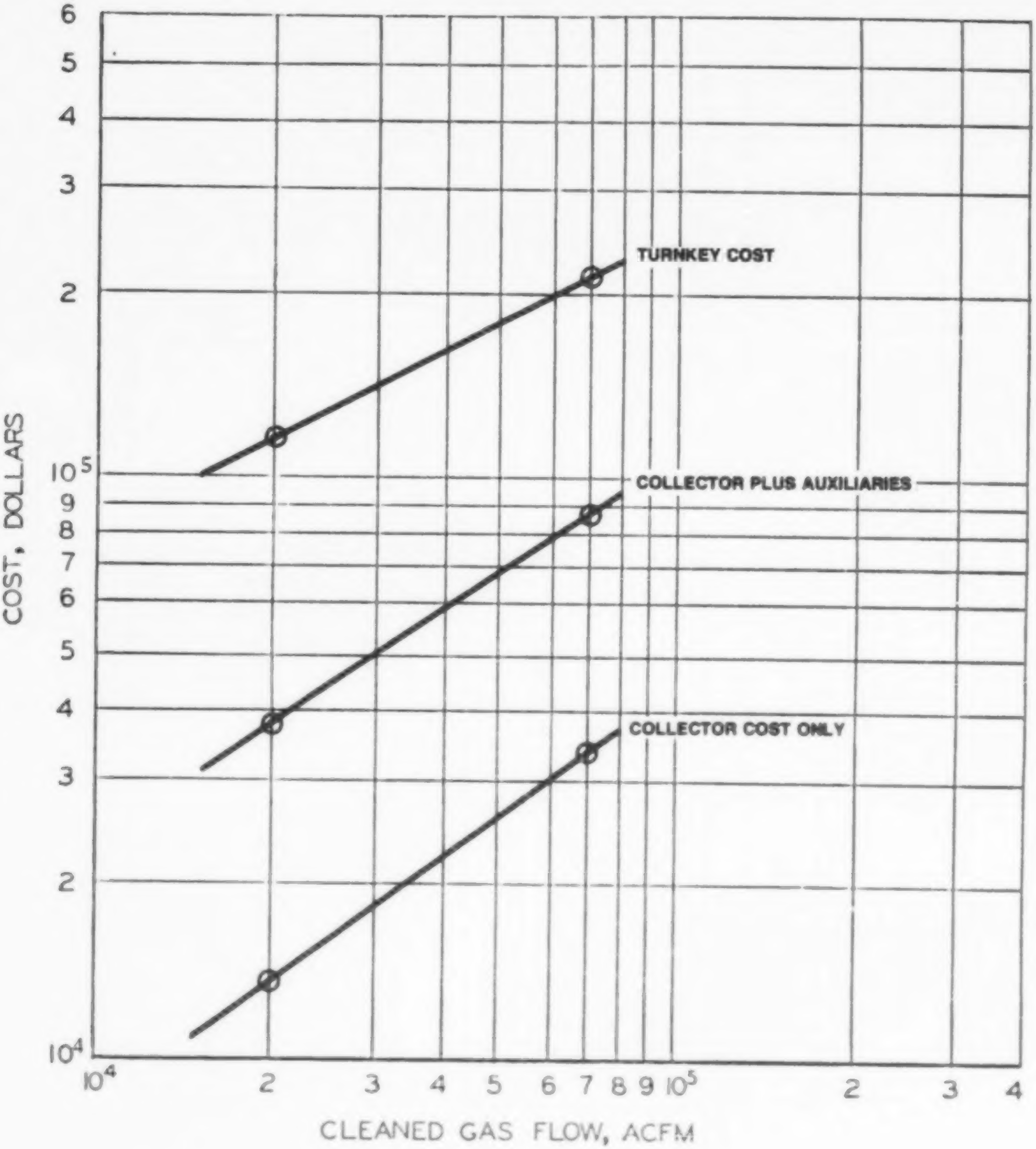


FIGURE 40

ANNUAL COST OF WET SCRUBBERS FOR SECONDARY AND TERTIARY ROCK CRUSHER
(Medium Efficiency)

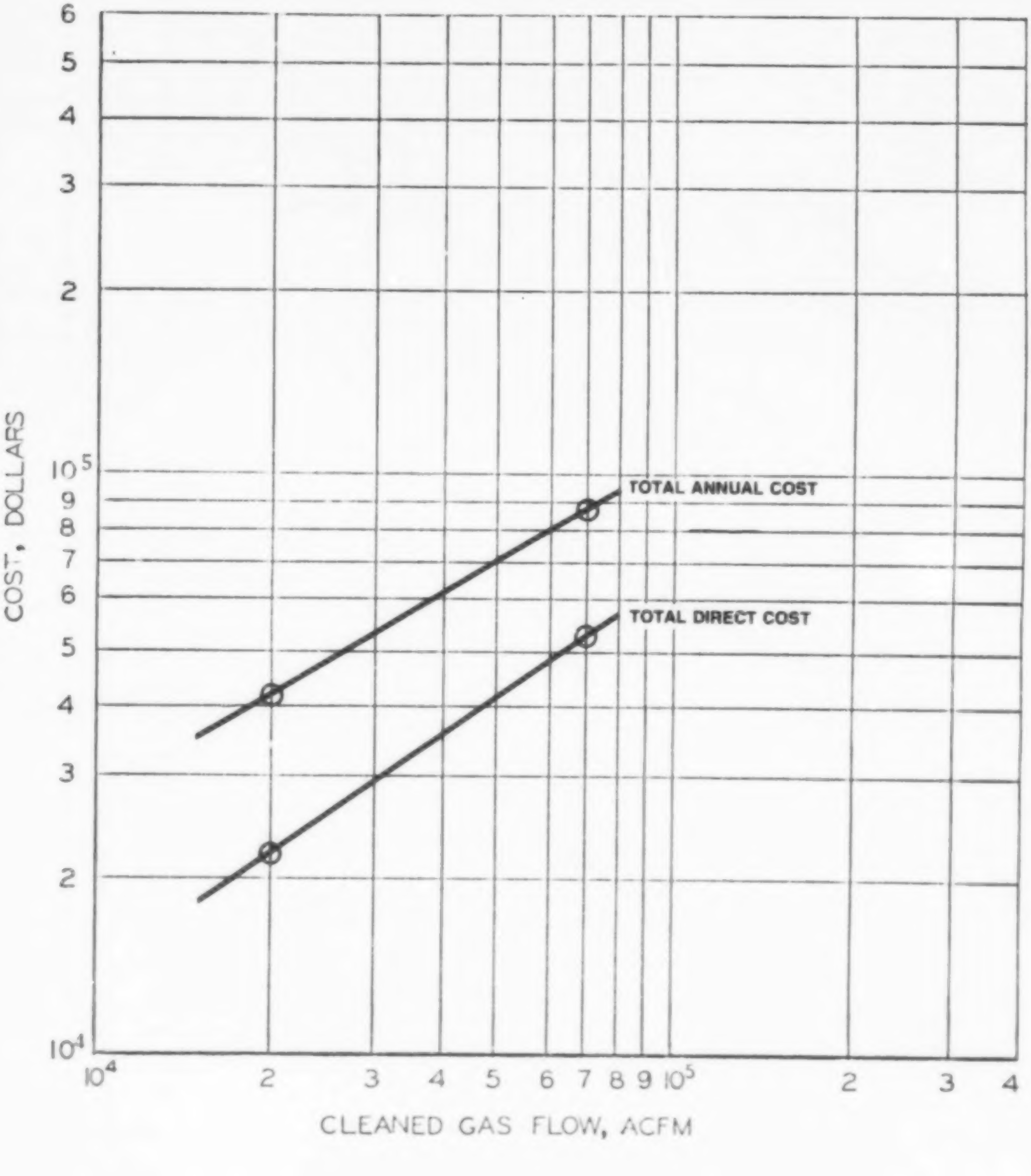


FIGURE 41

CAPITAL COST OF WET SCRUBBERS FOR SECONDARY AND TERTIARY ROCK CRUSHERS
(High Efficiency)

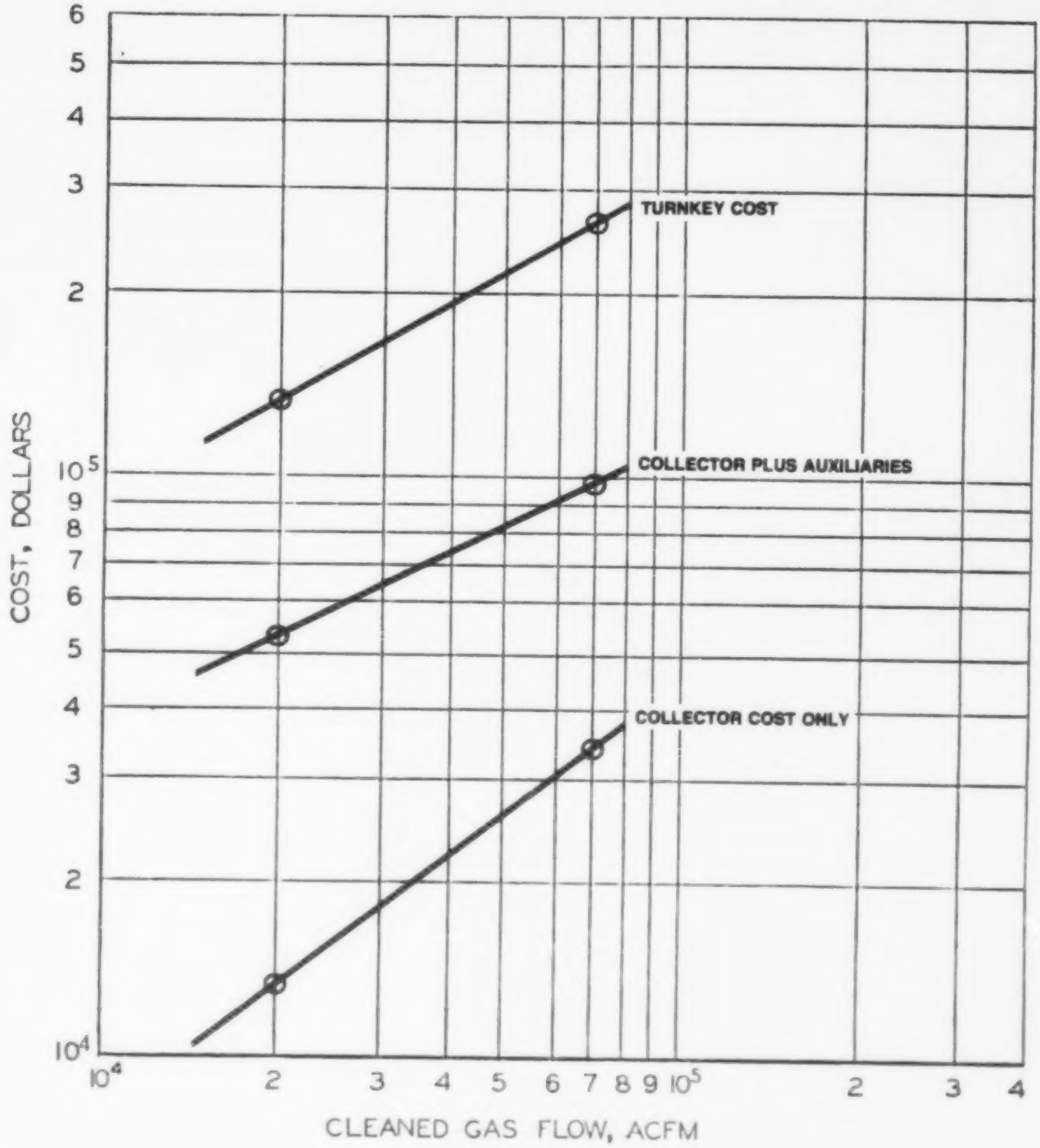


FIGURE 42

ANNUAL COST OF WET SCRUBBERS FOR SECONDARY AND TERTIARY ROCK CRUSHERS (High Efficiency)

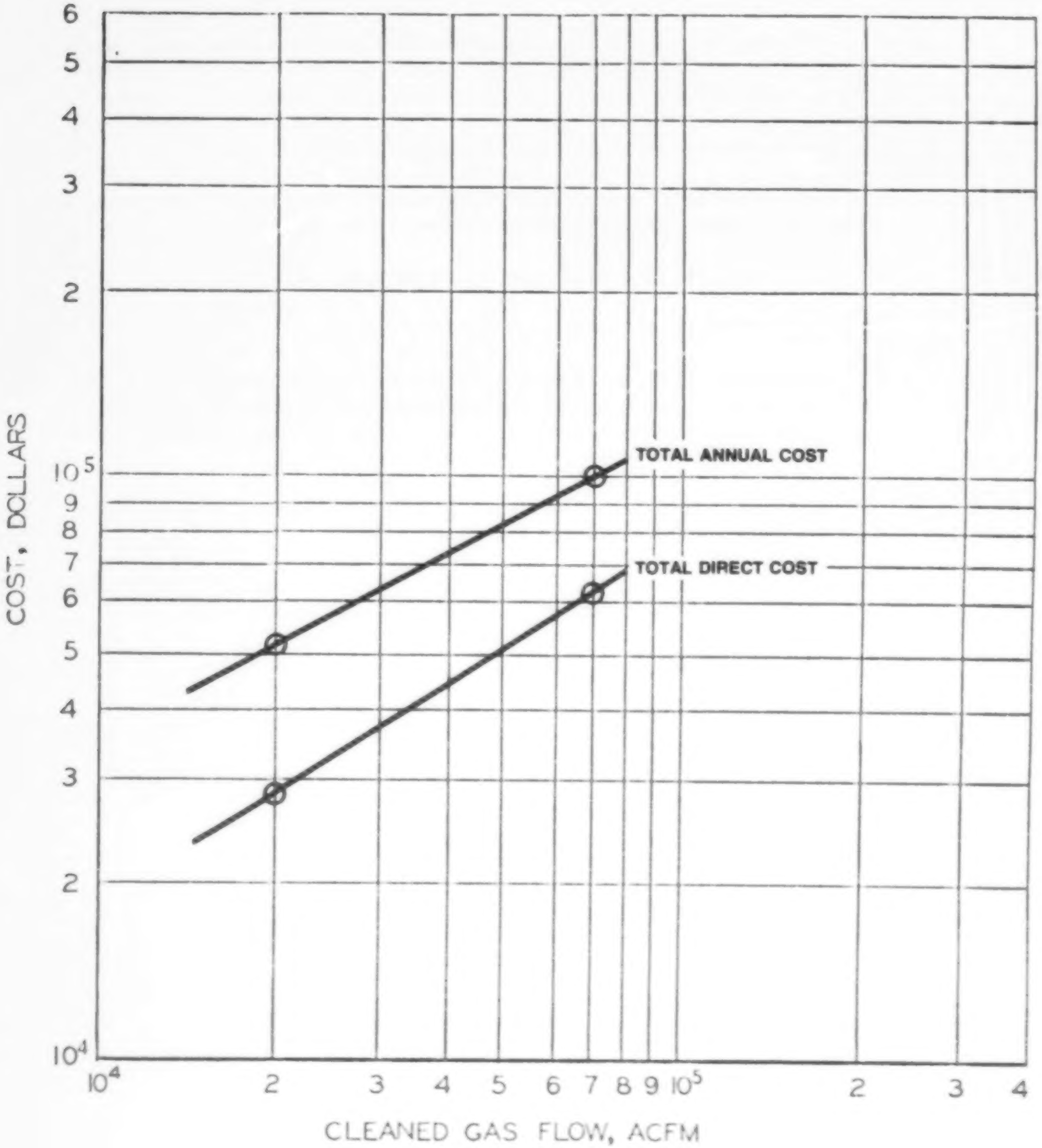


TABLE 66

WET SCRUBBER PROCESS DESCRIPTION

FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS SPECIFICATION

A scrubber is to remove the rock dust exhausted from the conveyor transfer points in a rock crushing plant. Hoods will be supplied by the bidder. Exhaust points will be ducted together and brought to the inlet of the scrubber. The number of hoods involved and their total face area is shown in the operating conditions. The inlet ductwork required will be 50 ft/hood. Duct velocity will be 3,500 ft/min.

The scrubber will be located in an open area. Fresh make-up water and sufficient power are available. The scrubbing system will consist of the following:

1. *Venturi scrubber with a cyclonic entrainment separator.*
2. *Recirculation tank and pumps.*
3. *Slurry settler, which will handle a portion of the recirculation pump discharge, and be capable of producing a reasonably thickened underflow product while returning water treated to minimize solids content. Slurry withdrawal should be set to maintain 10% (by weight) solids when operating at design capacity.*
4. *Two filters (one standby) to dewater the slurry product, capable of producing a cake with a minimum 65% (by weight) solids.*
5. *Fan sized with at least 20% excess capacity when operating at the design pressure and not more than 90% of the maximum recommended operating speed.*
6. *Necessary controls.*
7. *Carbon steel construction.*

TABLE 67

WET SCRUBBER OPERATING CONDITIONS

FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS SPECIFICATION

Two sizes of wet scrubbers are to be quoted for each of two efficiency levels. Vendor's quotations should consist of four separate and independent quotations.

	Small	Large
No. of Hoods Ducted Together	3	8
Total Face Area of Hoods, ft^2	71	234
Inlet Gas		
Flow, ACFM	5,000	15,000
Temp., °F	80	80
Flow, SCFM	4,900	14,700
Solids Loading		
gr/ACF	1.0	1.0
gr/DSCF	1.08	1.08
lb/hr	42.7	128
Medium Efficiency		
Flow, ACFM	5,000	15,000
Scrubber, ΔP, in. w.c.	*	*
Solids Loading		
gr/ACF	0.04	0.04
gr/DSCF	0.045	0.045
lb/hr	1.7	5.1
Collector Efficiency, wt %	96	96
High Efficiency		
Flow, ACFM	5,000	15,000
Scrubber, ΔP, in. w.c.	*	*
Solids Loading		
gr/ACF	0.01	0.01
gr/DSCF	0.011	0.011
lb/hr	0.4	1.3
Collector Efficiency, wt %	99	99

*To be supplied by vendor as a part of his quotation. Vendor should also supply required liquid circulation rate.

TABLE 68

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	5,000	15,000	5,000	15,000
°F	80	80	80	80
SCFM	4,900	14,700	4,900	14,700
Moisture Content, Vol. %	2	2	2	2
Effluent Contaminant Loading				
gr/ACF	1.0	1.0	1.0	1.0
lb/hr	42.7	128	42.7	128
Cleaned Gas Flow				
ACFM	5,000	15,000	5,000	15,000
°F	80	80	80	80
SCFM	4,900	14,700	4,900	14,700
Moisture Content, Vol. %	2	2	2	2
Cleaned Gas Contaminant Loading				
gr/ACF	.04	.04	.01	.01
lb/hr	1.7	5.1	.4	1.3
Cleaning Efficiency, %	96	96	99	99
(1) Gas Cleaning Device Cost	7,322	12,472	7,175	12,511
(2) Auxiliaries Cost				
(a) Fan(s)	2,093	3,991	4,151	7,649
(b) Pump(s)	1,345	2,087	1,348	2,087
(c) Damper(s)	1,099	2,798	1,099	2,798
(d) Conditioning, Equipment	2,963	3,063	3,000	3,063
(e) Dust Disposal Equipment	6,554	11,554	6,554	11,554
(3) Installation Cost				
(a) Engineering (b) Foundations & Support Ductwork Stack Electrical Piping Insulation Painting Supervision Startup	56,321	70,136	58,123	71,802
Performance Test Other	2,333	2,333	2,333	2,333
(4) Total Cost	80,030	108,434	83,783	113,797

TABLE 69

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS
FOR CONVEYOR TRANSFER POINTS

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,500					
Operating Labor (if any)					
Operator	$6/hr.				
Supervisor	$8/hr.	5,212	6,121	5,212	6,121
Total Operating Labor		5,212	6,121	5,212	6,121
Maintenance					
Labor	$6/hr.	1,200	1,200	1,200	1,200
Materials		570	690	670	790
Total Maintenance		1,770	1,890	1,870	1,990
Replacement Parts		1,867	2,250	2,225	2,593
Total Replacement Parts		1,867	2,250	2,225	2,593
Utilities					
Electric Power	$0.011/kwh	1,708	5,550	2,464	7,202
Fuel					
Water (Process)	$0.25/MGal	8	24	8	25
Water (Cooling)					
Chemicals, Specify					
Total Utilities		1,716	5,574	2,472	7,227
Total Direct Cost		10,565	15,835	11,779	17,931
Annualized Capital Charges	16% of Cap	12,805	17,349	13,405	18,208
Total Annual Cost		23,370	33,184	25,184	36,139

FIGURE 43

CAPITAL COST OF WET SCRUBBERS FOR CONVEYOR TRANSFER POINTS FOR CRUSHED STONE AND AGGREGATE INDUSTRY

(Medium Efficiency)

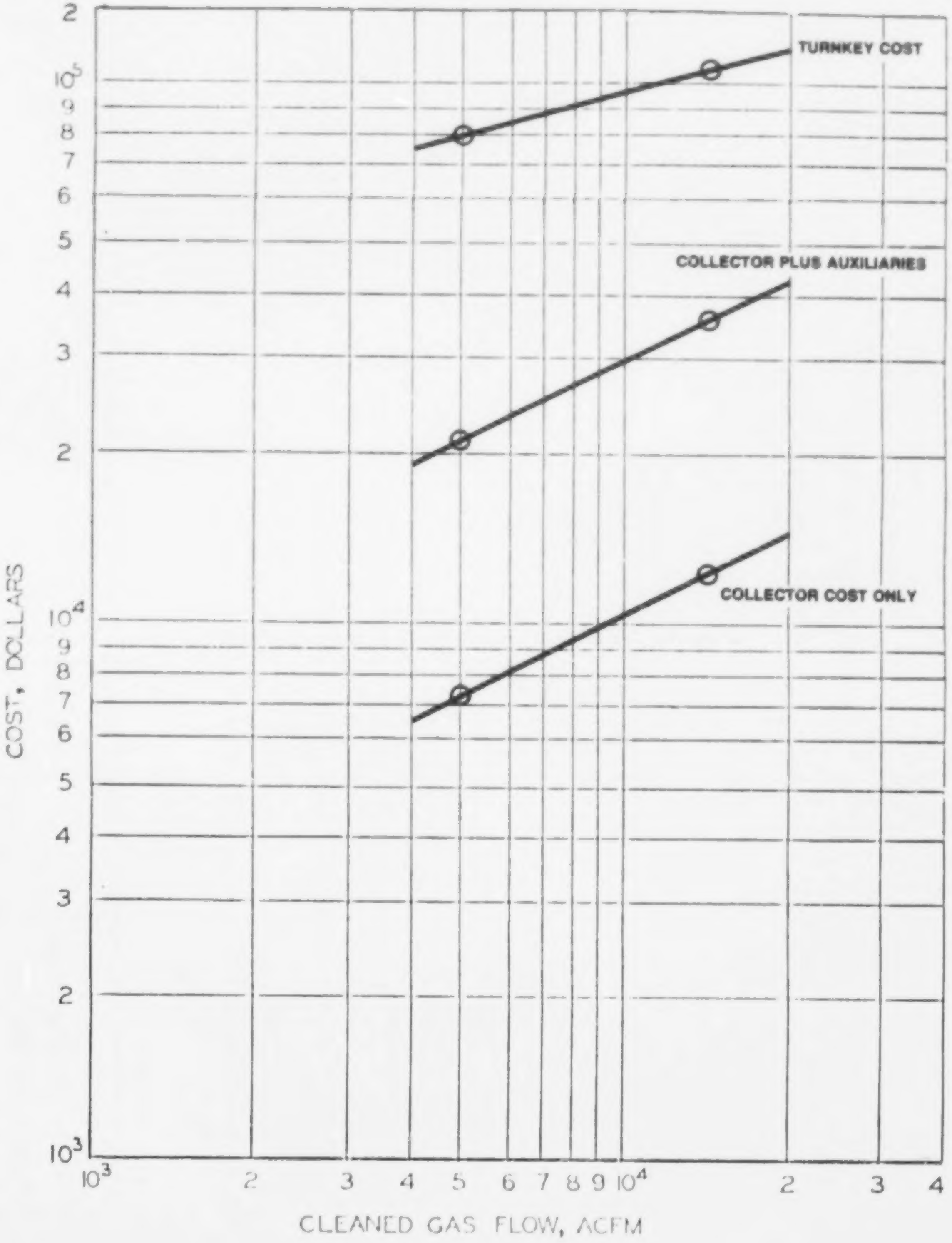


FIGURE 44

ANNUAL COST OF WET SCRUBBERS FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

(Medium Efficiency)

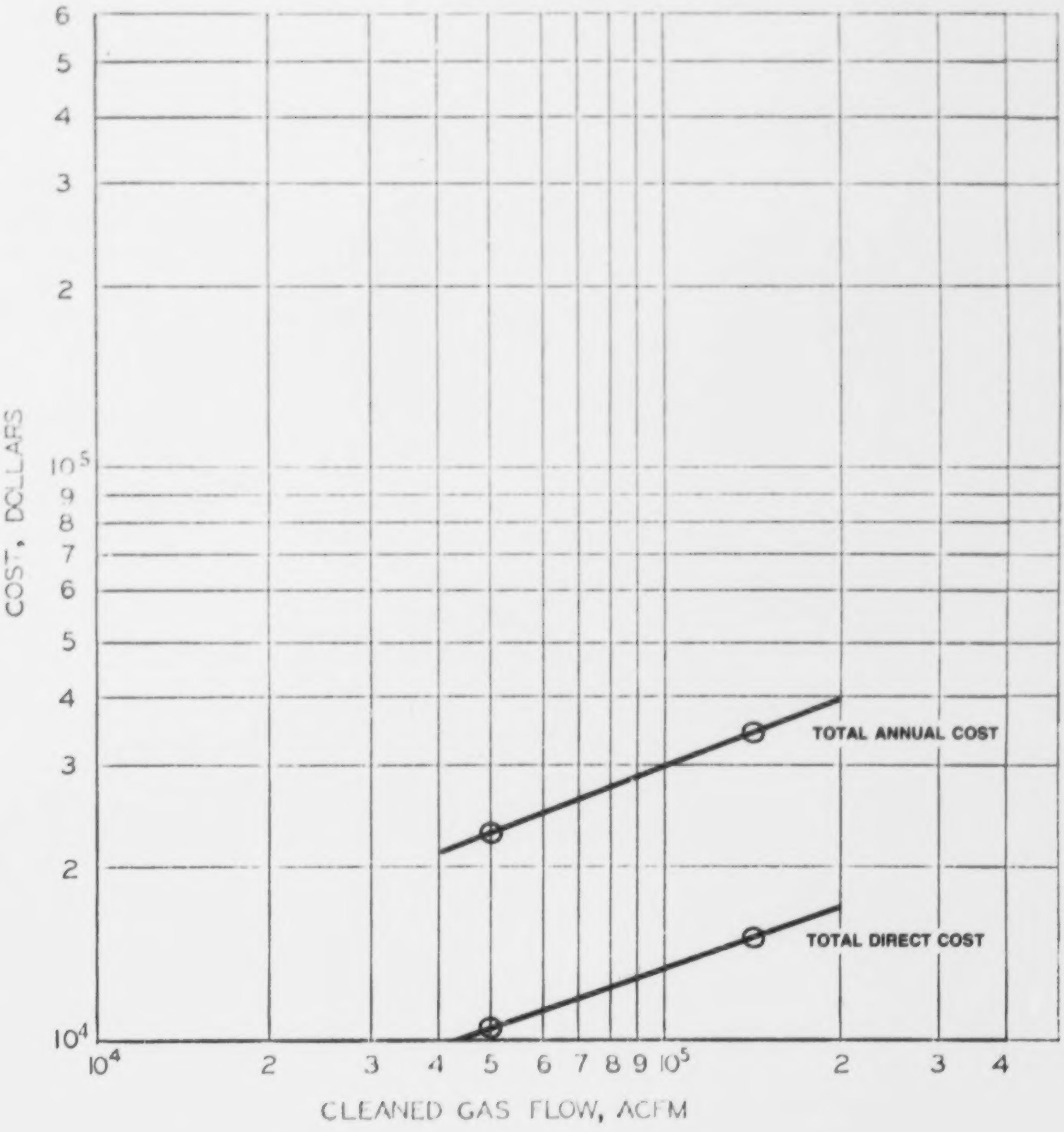


FIGURE 45

CAPITAL COST OF WET SCRUBBERS FOR CONVEYOR TRANSFER FOINTS FOR CRUSHED STONE AND AGGREGATE INDUSTRY (High Efficiency)

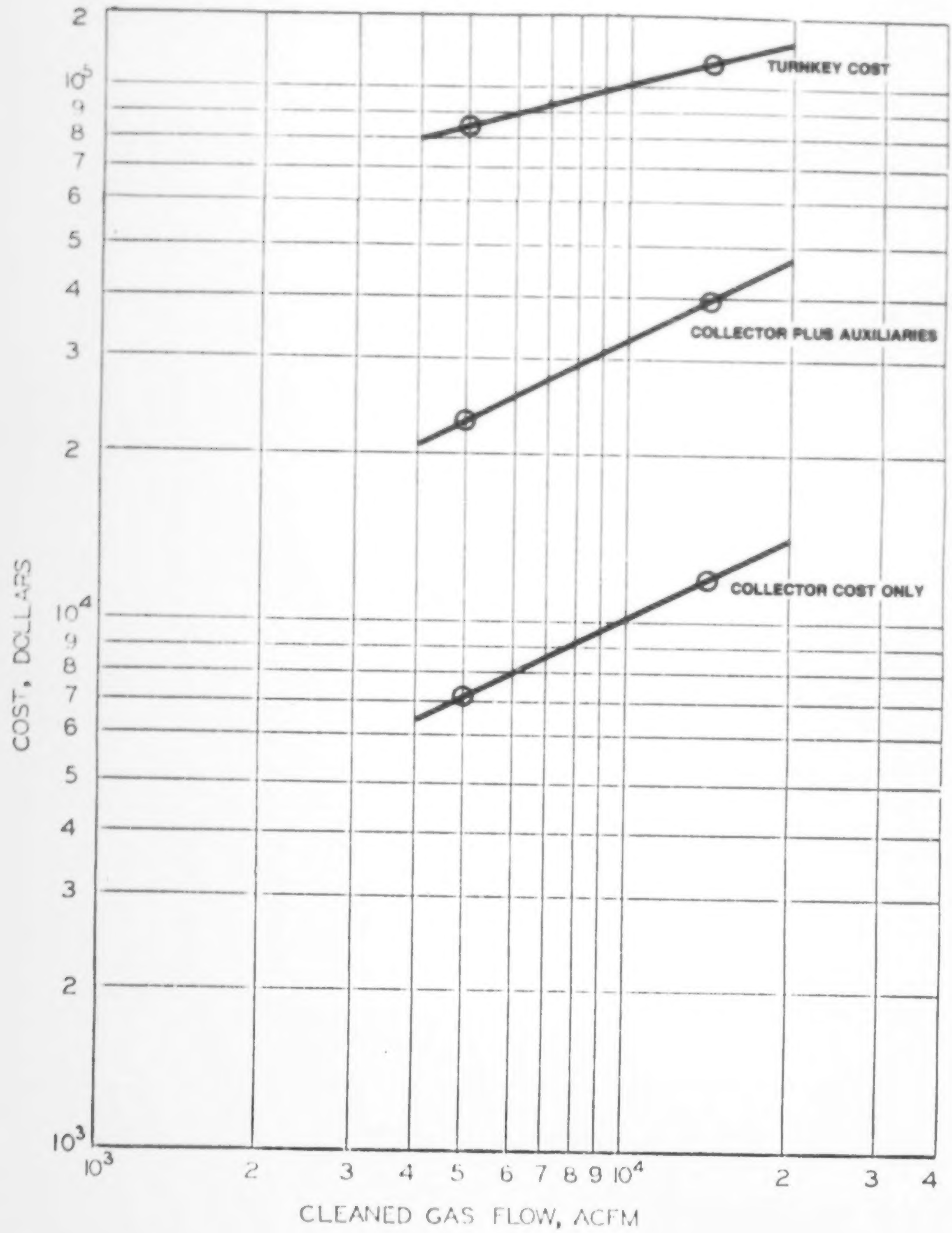


FIGURE 46

ANNUAL COST OF WET SCRUBBERS FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS (High Efficiency)

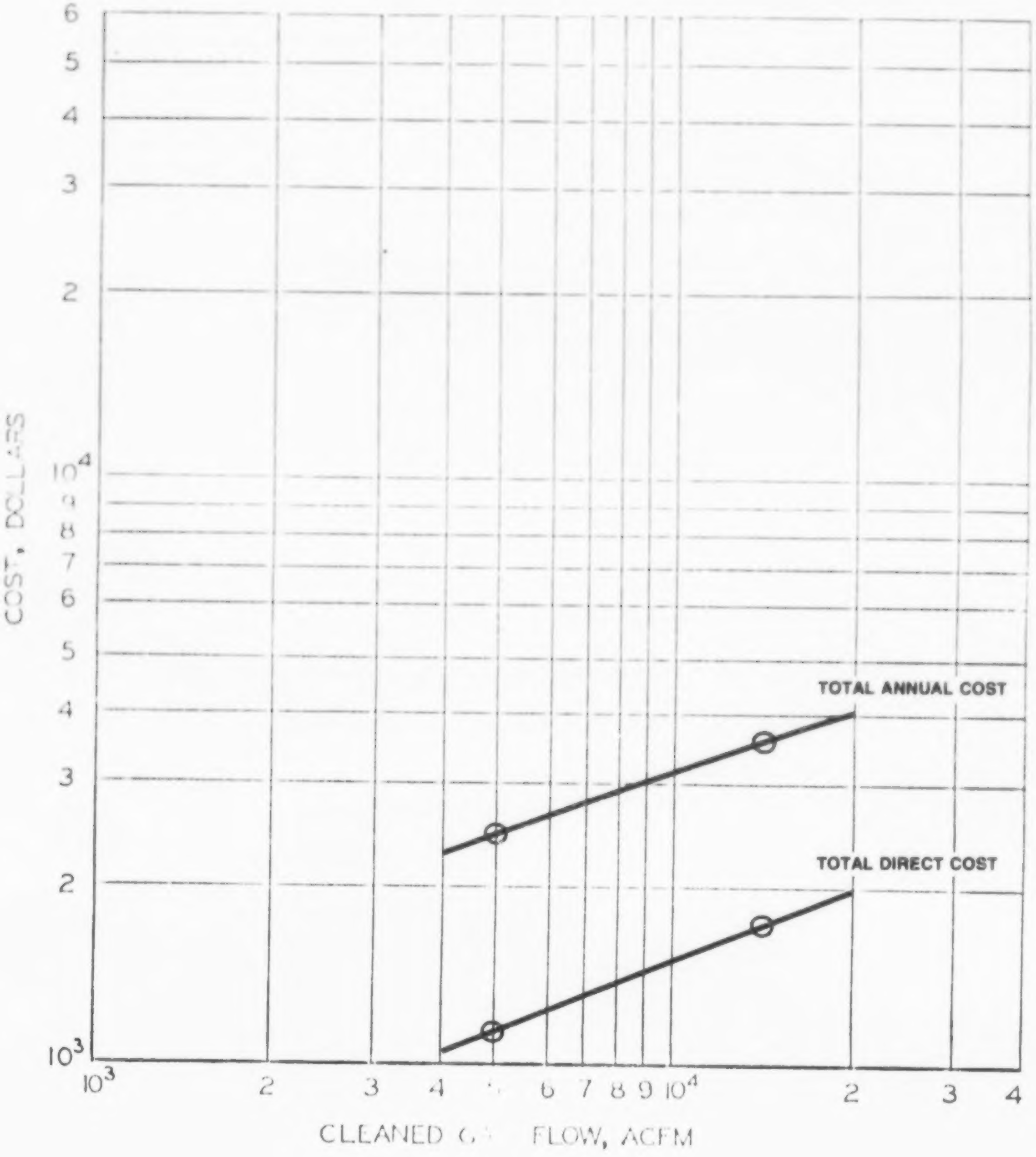


TABLE 70

FABRIC FILTER PROCESS DESCRIPTION

FOR SECONDARY AND TERTIARY ROCK CRUSHER SPECIFICATION

A fabric filter is to remove rock dust from the exhaust from the ventilation hoods located over the secondary and tertiary crushers of a rock crushing plant. Hoods will be supplied by the bidder.

The exhaust gases will be ducted together and brought to the inlet of the fabric filter. The amount of inlet ductwork required will be 100 ft. The fabric filter will be located in an area free from space limitations. A fan located at the outlet of the fabric filter will draw the exhaust gases through the system.

The fabric filter is to be compartmented to allow for isolation of an individual compartment for cleaning during operation. A single compartment should have a maximum of 25% of the total collecting surface area. Each section should also be capable of isolation for maintenance and have provisions for personnel safety during filter operation. No more than two bags must be removed to permit access to all of the bags. The dust collecting process should be continuous and should include the following:

1. Compartmented fabric filter operating at negative pressure.
2. Maximum air-to-cloth ratio, when one compartment is down for cleaning, of 5.0/1.
3. Dacron polyester bags.
4. Pulse-jet type cleaning mechanism.
5. Trough hoppers with a minimum side and valley angle of 55°.
6. Screw conveyor system with a rotary air lock at its end.
7. Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

TABLE 71

FABRIC FILTER OPERATING CONDITIONS

FOR SECONDARY AND TERTIARY ROCK CRUSHER SPECIFICATION

	Small	*Large*
Process Wt., ton/hr	*300*	*1,200*
No. of Crushers Hooded Together	*2*	*2*
Inlet Gas		
Flow, ACFM	*20,000*	*70,000*
Temp., °F	*80*	*80*
Flow, SCFM	*19,600*	*68,700*
Solids Loading		
gr/ACF	*5.25*	*6.00*
gr/DSCF	*5.70*	*6.50*
lb/hr	*900*	*3,600*
High Efficiency		
Flow, ACFM	*20,000*	*70,000*
Solids Loading		
gr/ACF	*0.01*	*0.01*
gr/DSCF	*0.011*	*0.11*
lb/hr	*1.7*	*6.0*
*Air-to-cloth Ratio**		
Collector Efficiency, wt %	*99.8*	*99.8*

**To be supplied by vendor as a part of his quotation.*

TABLE 72

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR FABRIC FILTERS
FOR SECONDARY AND TERTIARY ROCK CRUSHERS

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			20,000	70,000
°F			80	80
SCFM			19,600	68,700
Moisture Content, Vol. %			2	2
Effluent Contaminant Loading				
gr/ACF			5.25	6.0
lb/hr			900	3,600
Cleaned Gas Flow				
ACFM			20,000	70,000
°F			80	80
SCFM			19,600	68,700
Moisture Content, Vol. %			2	2
Cleaned Gas Contaminant Loading				
gr/ACF			.01	0.01
lb/hr			1.7	6.0
Cleaning Efficiency, %			99.8	99.8
(1) Gas Cleaning Device Cost			35,166	106,114
(2) Auxiliaries Cost				
(a) Fan(s)			6,177	24,096
(b) Pump(s)				
(c) Damper(s)			825	1,072
(d) Conditioning, Equipment			4,557	8,143
(e) Dust Disposal Equipment			6,316	15,346
(3) Installation Cost				
(a) Engineering			38,437	112,151
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test			2,000	2,000
Other				
(4) Total Cost			93,478	268,922

FIGURE 47

CAPITAL COST OF FABRIC FILTERS FOR SECONDARY AND TERTIARY ROCK CRUSHERS

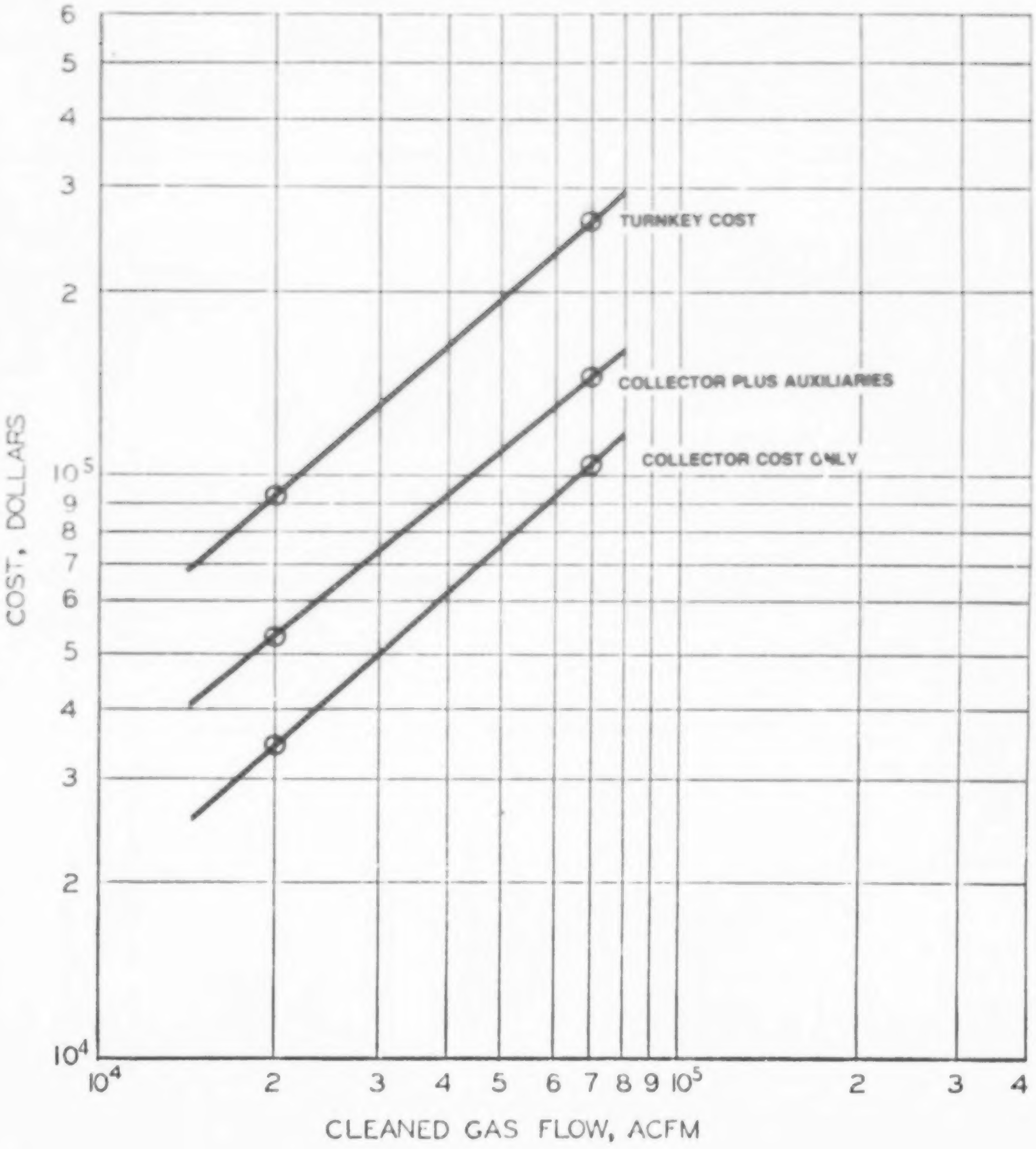


TABLE 73

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS
FOR SECONDARY AND TERTIARY ROCK CRUSHERS

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,500					
Operating Labor (if any)					
Operator	$8/hr			453	453
Supervisor					
Total Operating Labor				453	453
Maintenance					
Labor	$6/hr			504	1,240
Materials				133	433
Total Maintenance				637	1,673
Replacement Parts				2,142	7,541
Total Replacement Parts				2,142	7,541
Utilities					
Electric Power	$0.011/kwh			6,203	21,784
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities				6,203	21,784
Total Direct Cost				9,435	31,451
Annualized Capital Charges	16% of Cap			14,956	43,028
Total Annual Cost				24,391	74,479

FIGURE 48

ANNUAL COST OF FABRIC FILTERS FOR SECONDARY AND TERTIARY ROCK CRUSHERS

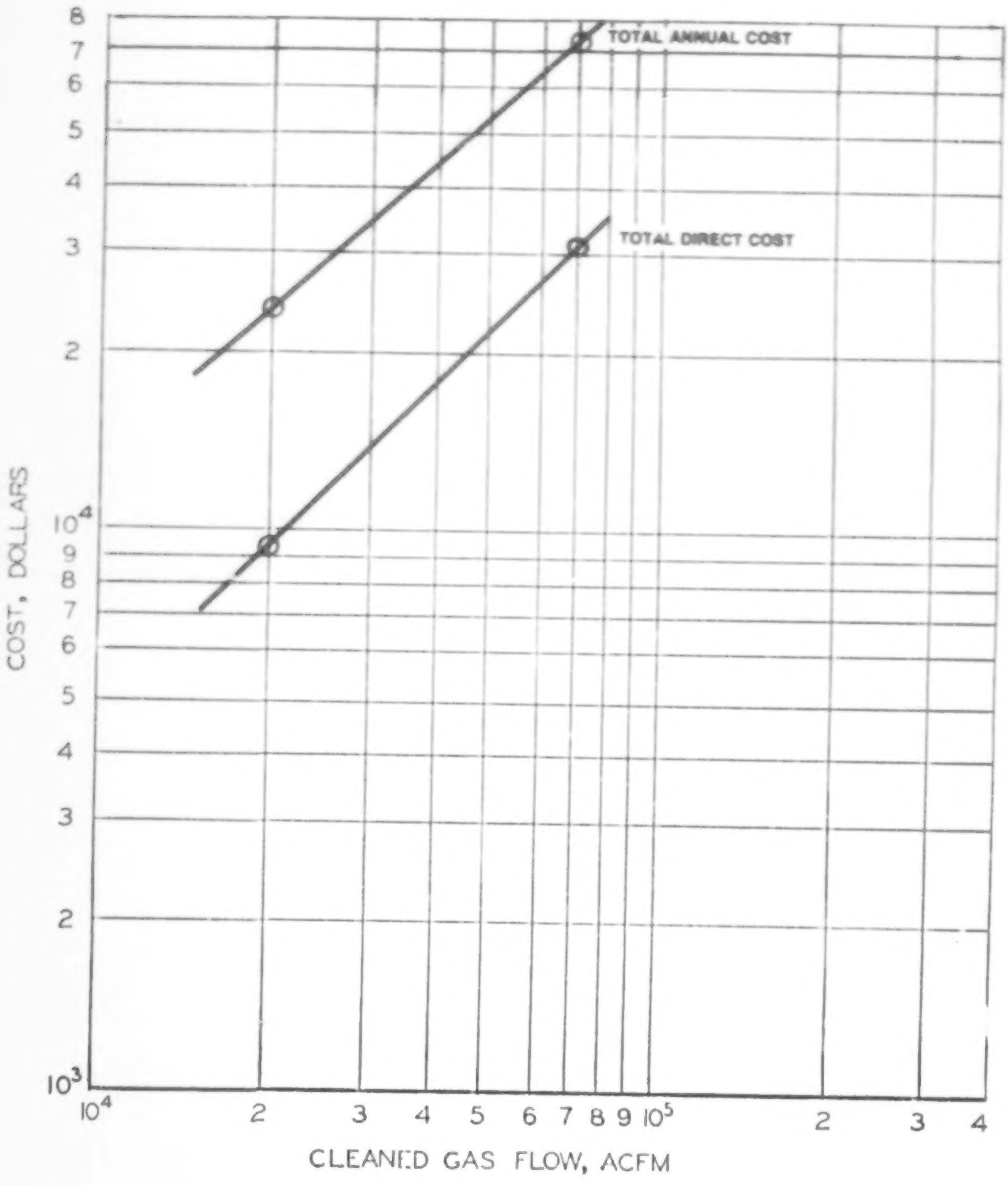


TABLE 74

FABRIC FILTER PROCESS DESCRIPTION

FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS SPECIFICATION

A fabric filter is to remove rock dust from the exhaust from ventilation hoods located at conveyor transfer points in a rock crushing plant. Hoods will be supplied by the bidder. Duct velocity will be 3,500 ft/min.

The exhaust gases will be ducted together and brought to the inlet of the fabric filter. The number of hoods involved and the total face area under all of the hoods is shown in the table of operating conditions. The inlet ductwork required will be 50 ft/hood. The fabric filter will be located in an area free from space limitations. A fan located at the outlet of the fabric filter will draw the exhaust gases through the system.

The fabric filter is to be compartmented to allow for isolation of an individual compartment for cleaning during operation. A single compartment should have a maximum of 25% of the total collecting surface area. Each section should also be capable of isolation for maintenance and have provisions for personnel safety during filter operation. No more than two bags must be removed to permit access to all of the bags. The dust collecting process should be continuous and should include the following:

1. *Compartmented fabric filter operating at negative pressure.*
2. *Maximum air-to-cloth ratio, when one compartment is down for cleaning, of 6.0/1.*
3. *Dacron polyester bags.*
4. *Pulse-jet type cleaning mechanism.*
5. *Trough hoppers with a minimum side and valley angle of 55°.*
6. *Screw conveyor system equipped with rotary air lock.*
7. *Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.*

TABLE 75

FABRIC FILTER OPERATING CONDITIONS

FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS SPECIFICATION

	Small	*Large*
No. of Hoods Ducted Together	*3*	*8*
Total Face Area of Hoods, ft²	*71*	*234*
Inlet Gas		
Flow, ACFM	*5,000*	*15,000*
Temp., °F	*80*	*80*
Flow, SCFM	*4,900*	*14,700*
Solids Loading		
gr/ACF	*1.0*	*1.0*
gr/DSCF	*1.08*	*1.08*
lb/hr	*42.7*	*128*
High Efficiency		
Flow, ACFM	*5,000*	*15,000*
Solids Loading		
gr/ACF	*0.01*	*0.01*
gr/DSCF	*0.011*	*0.011*
lb/hr	*0.4*	*1.3*
*Air-to-cloth Ratio**		
Collector Efficiency, wt %	*99*	*99*

**To be supplied by vendor as a part of his quotation.*

TABLE 76

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR FABRIC FILTERS
FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			5,000	15,000
°F			80	80
SCFM			4,900	14,700
Moisture Content, Vol. %			2	2
Effluent Contaminant Loading				
gr/ACF			1.0	1.0
lb/hr			42.7	128
Cleaned Gas Flow				
ACFM			5,000	15,000
°F			80	80
SCFM			4,900	14,700
Moisture Content, Vol. %			2	2
Cleaned Gas Contaminant Loading				
gr/ACF			.01	.01
lb/hr			.4	1.3
Cleaning Efficiency, %			99	99
(1) Gas Cleaning Device Cost			10,290	22,297
(2) Auxiliaries Cost				
(a) Fan(s)			2,041	4,772
(b) Pump(s)				
(c) Damper(s)			83	109
(d) Conditioning, Equipment			2,093	3,925
(e) Dust Disposal Equipment			1,230	3,435
(3) Installation Cost				
(a) Engineering			12,683	25,211
(b) Foundations & Support				
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test			2,000	2,000
Other				
(4) Total Cost			30,420	61,749

FIGURE 49

CAPITAL COST OF FABRIC FILTERS FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

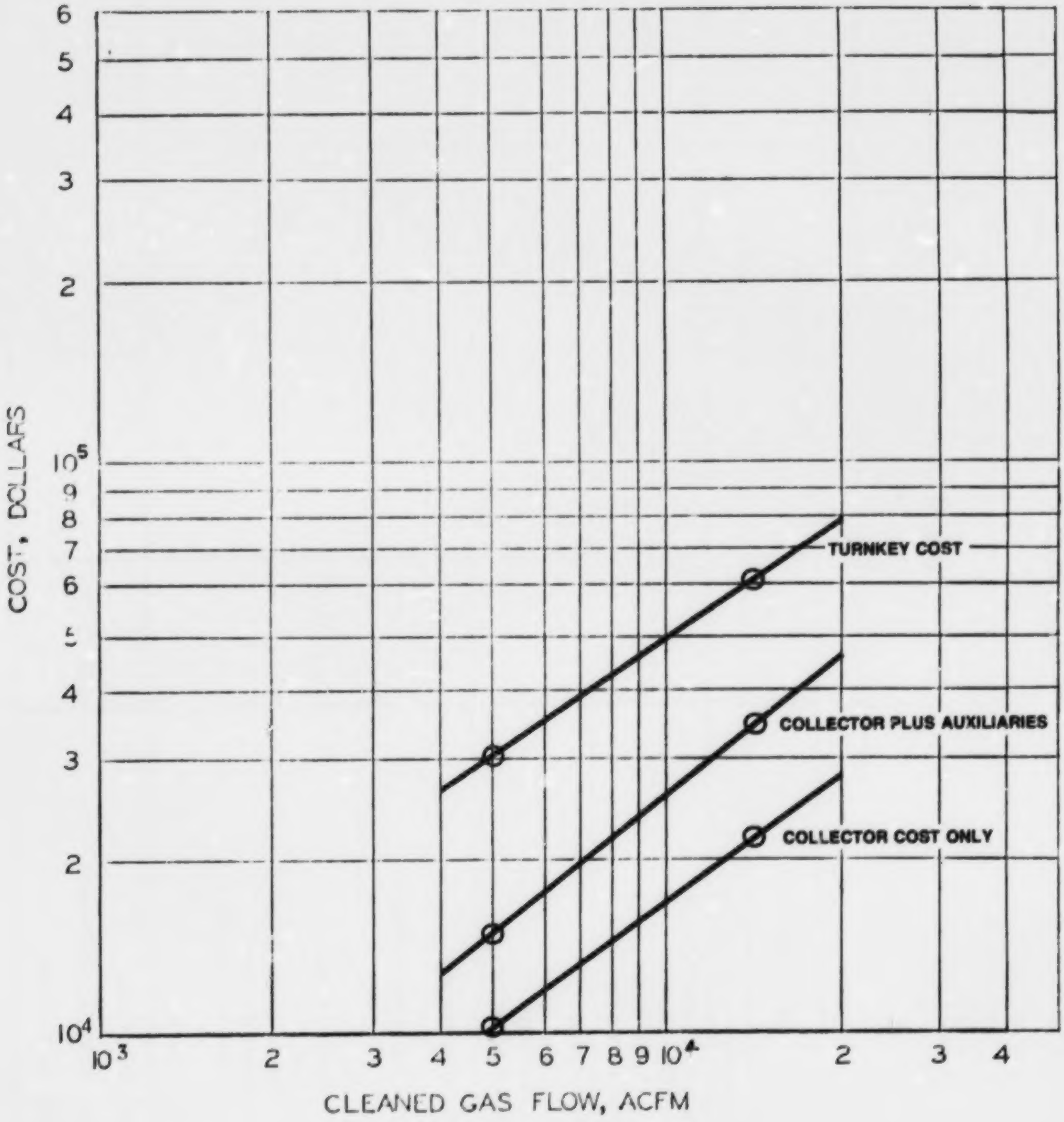


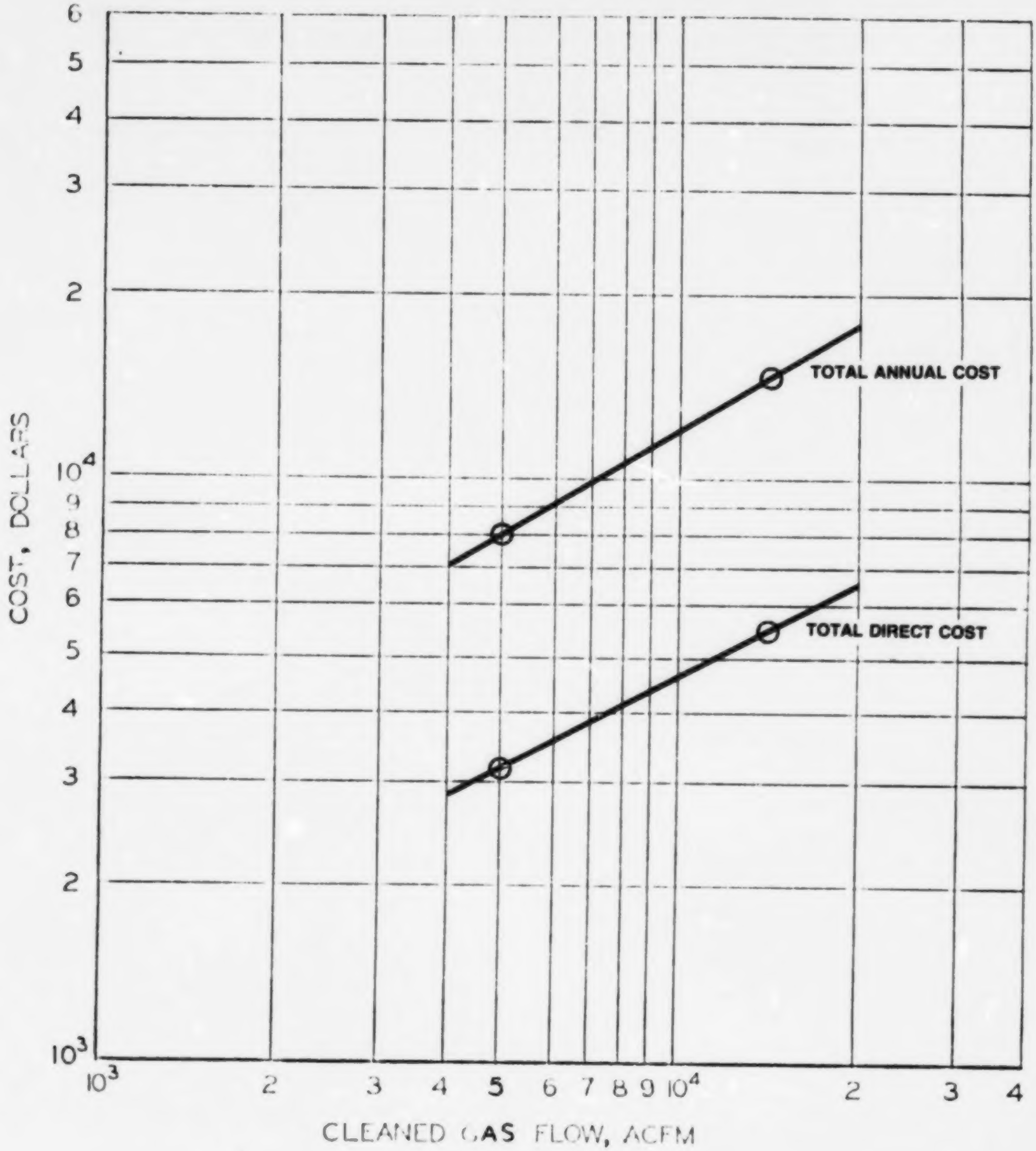
TABLE 77

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS
FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 8,500					
Operating Labor (if any)					
Operator					
Supervisor	$8/hr			453	453
Total Operating Labor				453	453
Maintenance					
Labor	$6/hr			304	416
Materials				40	90
Total Maintenance				344	506
Replacement Parts				493	1,150
Total Replacement Parts				493	1,150
Utilities					
Electric Power	$0.011/kwh			1,911	3,319
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities				1,911	3,319
Total Direct Cost				3,201	5,428
Annualized Capital Charges	16% of Cap			4,867	9,880
Total Annual Cost				8,068	15,308

FIGURE 50

ANNUAL COST OF FABRIC FILTERS FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS



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2. Guide to the Prevention and Suppression of Dust In Mining, Tunnelling and Quarrying, International Labour Office, Printed by Atar S.A., Geneva (Switzerland), 1965.

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6. ASPHALT SATURATION

Roofing paper and roofing shingles are manufactured by a process known as asphalt saturation. In this process a vegetable felt base is impregnated with petroleum derived asphalt materials which are called saturants. The felt is made from vegetable fibers and is often produced in the same facility as the finished roofing materials.

The industry producing these products consists of firms with a wide variation in size. The Census of Manufacturers shows 226 firms engaged in this industry in 1967.[1] The average firm employed 65 people and shipped $2.65 million of products. The complete distribution of firm sizes and product values is presented in Table 78. Total shipments by this industry in 1971 were 7.9 million tons and this figure was projected to grow at a rate of approximately 3% per year.

PROCESS DESCRIPTION

The asphalt saturation process involves basically the application of a controlled amount of asphalt to both sides of a dry felt sheet. The application is often carried out by spraying the felt with hot asphalt and then dipping the felt into a tank holding more hot asphalt. The dipping operation is usually totally enclosed with a hood which is vented to the atmosphere. A schematic flow diagram of the process is shown in Figure 51.

Raw Materials

There are two main raw materials used in the production of asphalt roofing; asphalt saturant and felt.

Asphalt is a petroleum derived product. It is produced as the residual bottoms product from the vacuum distillation of crude oil. It is principally hydrocarbon in nature, but also contains oxygen, sulfur, nitrogen, metals, and other trace elements chemically bonded to the hydrocarbon molecules. It is normally solid at room temperature, having an initial boiling point in excess of 1000°F.

Asphalt, as produced from a crude unit in a refinery, is not viscous enough to be used as saturant. Viscosity is increased by means of a treatment step called asphalt blowing. This treatment consists of bubbling air through liquid asphalt. Oxidation reactions occur during this treatment which lead to polymerization of the hydrocarbons and some reduction of the hydrogen content. In the roofing

TABLE 78

NUMBER OF ESTABLISHMENTS AND VALUE OF SHIPMENTS OF ASPHALT SATURATED PRODUCTS BY SIZE CLASS*

	Number of Establishments	Value of Shipments (million dollars)
1 to 4 Employees	33	5.6
5 to 9 Employees	22	10.2
10 to 19 Employees	33	29.6
20 to 49 Employees	46	59.0
50 to 99 Employees	44	132.0
100 to 249 Employees	42	276.0
250 to 499 Employees	4	31.6**
500 to 999 Employees	2	53.8**
Total	226	597.8

*1967 Data

**Estimate, based on output per employee

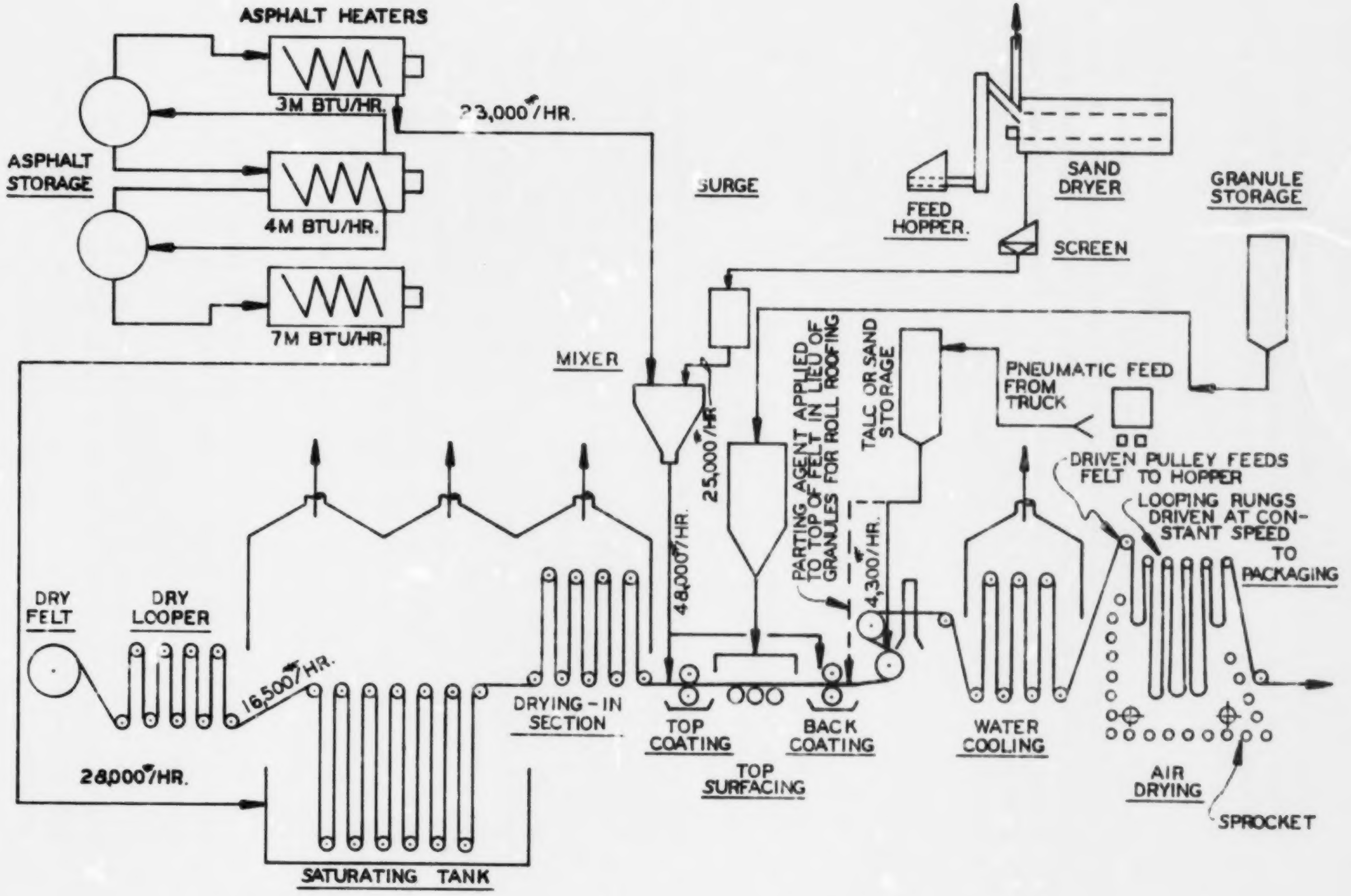

ASPHALT HEATERS
3M BTU/HR.
4M BTU/HR.
7M BTU/HR.
ASPHALT STORAGE
23,000#/HR.
SURGE
MIXER
FEED HOPPER.
SAND DRYER
SCREEN
GRANULE STORAGE
PNEUMATIC FEED FROM TRUCK
TALC OR SAND STORAGE
25,000#/HR.
48,000#/HR.
PARTING AGENT APPLIED TO TOP OF FELT IN LIEU OF GRANULES FOR ROLL ROOFING
4,300#/HR.
DRIVEN PULLEY FEEDS FELT TO HOPPER
LOOPING RUNGS DRIVEN AT CONSTANT SPEED
TO PACKAGING
DRY FELT
DRY LOOPER
16,500#/HR.
28,000#/HR.
SATURATING TANK
DRYING-IN SECTION
TOP COATING
TOP SURFACING
BACK COATING
WATER COOLING
AIR DRYING
SPROCKET

FIGURE 51

SCHEMATIC FLOW DIAGRAM OF ASPHALT SATURATION PROCESS[3] products industry, the air-blown asphalt is called saturant (or coating asphalt) and is characterized by its softening point which is typically 100 to 140°F. In the saturating process, it is handled at 400 to 500°F where it is fluid enough to be applied to the felt in controlled thicknesses.

Felt is a fibrous paper product produced from vegetable matter. It is commonly characterized by two properties: weight and moisture content. Weight is a term for the thickness of the felt. Several standard felt weights are produced for use in different products. Moisture content of the felt is an important property since it affects the quality of the saturator product. Excessive moisture can cause the applied asphalt to blister. Felts are generally made with 5 to 10% moisture, an amount which can be adequately removed during saturation.

Non-Coated Products

These products are commonly referred to as 15 and 30 pound asphalt saturated rag felt (ASRF). Fifteen pound ASRF is made from organic felt, 36 inches wide and with a felt weight of 5.6 pounds per 100 square feet. Thirty pound ASRF is made from organic felt 36 inches wide and with a felt weight of 10.4 pounds per 100 square feet. The organic felt is commonly referred to as 27 weight and 50 weight. The organic felt is wound into jumbo rolls that weigh from 2,000 to 3,000 pounds, with up to 7,000 lineal feet per roll.

During operation the felt is unrolled continuously onto a series of rollers called a dry looper. The dry looper acts as inventory at the front of the process so that the feed rate to the saturator can be held constant, even during felt roll changes. Felt from the dry looper is pulled into the saturator where it is saturated with hot asphalt at a temperature of 450°F. Saturation is accomplished by spraying, dipping, or both. When spraying is employed, hot asphalt is sprayed onto one side of the felt, driving the moisture out the other side. When both methods are employed, spraying precedes dipping. Most modern roofing plants are designed to use dipping only, since the dipping process removes a sufficient amount of moisture out of the felt by boiling during submersion in the asphalt bath.

After the felt is dipped, it travels over several rolls known as the drying-in section. This allows the surface saturant to dry into the felt and helps coat the sheet.

The felt is then conveyed to an accumulator before it is wound into rolls. Roll lengths vary from 72 to 144 feet. The 27w felt generally absorbs or retains approximately 7.8 pounds of saturant per 100 square feet. The 50w felt retains approximately 17.4 pounds of saturant per 100 square feet.

The process production rate is controlled by the linear speed at which felt can be fed to the saturator and that speed, in turn, is controlled by the properties of the felt. Maximum speeds are lower for heavier weight felts than for lighter weight felts. Speeds as high as 1,000 fpm can be used with light weight felts, but average speed is about 350 fpm. If 50w felt is fed to a saturator at 350 fpm, the weight rate of felt feed is 6552 lb/hr and the production rate of saturated product is 17,514 lb/hr.

Coated and Slate Surfaced Products

Asphalt shingles are generally produced using a 55w organic felt that weighs 11.5 pounds per 100 square feet. Production of asphalt shingles begins with the asphalt saturation process and then goes through a coating and surfacing process. The coating process is accomplished by metering a measured amount of filled coating to both surfaces of the saturated felt. The shingle weight is controlled in the coating process by increasing or decreasing the amount of surface coating.

Filled coating is made from two materials, coating and filler. There are two types of filler that are normally used; limestone and slate. The majority of the roofing companies use 50% filler in the coating. The filled coating is applied to the sheet at temperatures ranging from 360 to 410°F.

After the coating process, the sheet travels through a surfacing section where slate granules are applied to the top surface and a parting agent is applied to the back surface. Different colors of granules are applied to the sheet to get the desired blend or color of shingles. Several different parting agents are available. Talc, sand and dolomite are the most common parting agents used. When the sheet leaves the surfacing section, it travels through a cooling section where water is sprayed on the back of the sheet. Then the sheet goes into an accumulator to further cool the sheet. When the sheet leaves the accumulator, it is cut into shingles and packaged.

The process production rate is controlled by the capabilities of the machine, such as, saturation capacity. Machine speeds on asphalt shingle production range from 350 to 600 fpm.

NATURE OF THE GASEOUS DISCHARGE

The saturator is totally enclosed with a hood for health reasons and that hood is vented to the atmosphere. The amount of air exhausted from this hood depends upon the size of the saturator and the degree of enclosure of the saturator. Typical saturators vent 20,000 to 30,000 ACFM. The range of rates extends from 10,000 to 68,000 ACFM.[1] The trend in modern plant design is down since the cost of the required pollution control equipment depends strongly upon the vent flow rate. The minimum exhaust volume is set by the quantity of air that will allow men to work in the saturator enclosure and that will prevent the escape of fumes into the plant.

The gases vented from the hood contain two principal classes of pollutants; hydrocarbons and sulfur oxides. The hydrocarbons originate from the hot asphalt bath. They enter the ventilation stream by means of vaporization from the bath and mechanical agitation of the bath caused by the felt passing through. Where spraying is used, the spray nozzles also contribute vaporized hydrocarbons. The hydrocarbons are emitted in both the gas phase and the liquid phase as an aerosol. The aerosol consists almost entirely of droplets formed by the condensation of oil vapors driven from the asphalt saturator, with little contribution from liquid particles entrained by mechanical agitation of the bath or at the spray nozzle. These particles are very small with most being submicron.

The sulfur oxides are all in the vapor phase. They are formed from the sulfur containing compounds in the asphalt and originate in the hot asphalt bath or sprays. Sulfur oxides are emitted at lower rates than hydrocarbons. Typical emission factors are as follows:[1]

Hydrocarbons	1 to 2.5 lb/ton product
Sulfur Oxides	0.05 to 0.20 lb/ton product

The asphalt blowing facilities represent the other major pollution source in the typical asphalt roofing products plant. The emissions are hydrocarbon in nature and result from the air blown through the asphalt to improve its properties as a saturant. The rate of emission is roughly 50% of the saturator.

POLLUTION CONTROL CONSIDERATIONS

The pollution control systems which are applicable to the emissions from asphalt saturators include some of those classically applied to control of hydrocarbons: incineration, and absorption processes using chemical oxidants. Glass fiber mat filters, specifically developed for use on asphalt saturators, are also commonly used.[3] Carbon adsorption is not used because the asphaltic hydrocarbons are not easily desorbed from the surface of the carbon. Conventional devices used for the collection of small sized particulate matter such as high energy wet scrubbers and electrostatic precipitators have been applied to a lesser degree.

Incinerators

Thermal incineration is the most positive and direct control method for hydrocarbon emissions and it has been widely applied to emissions from this process. Conversions up to 99% can be achieved at operating temperatures of 1,200 to 1,400°F and residence times of 0.3 sec. The units are built with heat recovery when the air flow being treated is large enough to make the economics attractive. The heat recovery scheme used takes one of two forms.

1. Preheat of the incinerator inlet gas by heat exchange with hot outlet gas.
2. Use of the heat in the hot outlet gas in some other part of the roofing products plant, e.g., to make steam for the felt manufacturing line.

Incineration can be quite effective. However, the operating cost can be high due to fuel consumption.

Catalytic incineration units have not been widely applied in this industry because of rapid deactivation of the catalysts, caused by sulfur and heavy metals in the asphalt.

Glass Fiber Mat Filters

Glass fiber mat filters have been specifically developed to control the emissions from asphalt saturators.[3] These filters consist of mats made from glass fibers and bonded together with phenolformaldehyde resins. The mats are constructed so that they are compressible. As air is passed through them they compress and effectively reduce the size of the passages through which the gas is flowing. This compression increases the collection efficiency of the filter. Collection efficiencies above 90% can be achieved at pressure drops of 16 to 18 in. w.c. (see Table 88) for increasing effluent velocities.[3]

Absorption Processes Using Chemical Oxidants

Chemical oxidation has been applied in some locations to control hydrocarbon emissions. The oxidation is carried out in a low energy wet scrubber, usually of the conventional packed tower design. The circulating scrubbing liquor is a dilute solution of oxidizing chemical such as potassium permanganate. These systems can be effective, but require large amounts of the oxidizing chemical to achieve an acceptable level of conversion and often produce solid and liquid waste products which must be disposed of. The following sample reaction demonstrates these problems:

$$2\,KMnO_{4\,(aq)} + -(CH_2)-_{(1)} \rightarrow 2MnO_{2\,(s)} + 2KOH_{(aq)} + CO_{2\,(g)}$$

In this example, two moles (316 lbs) of potassium permanganate are required to oxidize one mole (6 lbs) of carbon and hydrogen, and the reaction produces two moles (174 lbs) of solid manganese dioxide waste, and one mole (56 lbs) of potassium hydroxide which must be neutralized prior to disposal.

SPECIFICATIONS AND COSTS

Specifications were written for systems to control emissions from each of the two major sources in an asphalt roofing products plant: the asphalt saturator and the asphalt blow still.

Asphalt Saturator

Specifications were written for three types of control systems: thermal incinerators, glass fiber mat filters, and absorption using chemical oxidants. In each case, the specification requested costs for two independent saturator operations different from one another only in ventilation rate. The two units represent a new, low ventilation rate design and an older, higher ventilation rate design. Production rate, saturant and felt usage, and process operating conditions are assumed to be identical for the two cases.

Specifications for absorption systems using chemical oxidants are shown in Tables 79 and 80. Averaged capital and operating costs are presented in Tables 81 and 82 and in Figures 52 and 53. The systems were bid assuming that the scrubbing liquor would be a dilute, buffered solution of potassium permanganate. In this example, the costs of buffering and neutralization have not been included. The consumption rates of permanganate reflected in the operating costs presented in Table 82 are calculated values based upon theoretical reactions equivalent to that shown at the end of the previous section. The costs shown on this table do not reflect field or laboratory data.

Incinerator specifications are shown in Tables 83 and 84. Averaged capital and operating cost data are presented in Tables 85 and 86 and in Figures 54 and 55. The specifications requested costs at each of two levels of conversion; 98% and 99%. All of the bidders responded with identical capital costs and nearly identical operating costs for these two cases. The capital costs shown in Table 85 represent both conversion levels. The slightly different operating costs are reflected in Table 86 but could not be shown in Figure 54. In addition to cost data, the specification requested combustion data from the bidders. The averaged responses to this request are shown in the marked places in Table 84.

Glass fiber mat filter specifications are shown in Tables 87 and 88. These specifications were transmitted to the only available bidder who supplied the costs presented in Tables 89 and 90 and Figures 56 and 57. The specification requested costs and unit pressure drop at 98% (medium) collection efficiency and the expected pressure drop at 99% (high) collection efficiency. The pressure drop information is presented in Table 88.

TABLE 79

SCRUBBER PROCESS DESCRIPTION

FOR ASPHALT SATURATOR SPECIFICATION

A scrubber is to control hydrocarbon emissions from an asphalt saturator. Processing conditions and specifications are tabulated in Table 45.

The scrubbing liquor is to consist of a 3 wt % solution of potassium permanganate buffered to 9.0 pH with borax. Materials of construction should be consistent with the permanganate solution. Bids should include the following items:

1. *Low energy wet scrubber and mist eliminator.*
2. *Necessary fans and motors.*
3. *Twenty foot stack.*
4. *Recirculating tank.*
5. *Permanganate makeup and storage tank.*
6. *Interconnecting ductwork for all equipment furnished.*
7. *Appropriate control system.*
8. *Necessary provisions for periodic cleaning of manganese dioxide residue.*

All of the above, except the scrubber proper, should be treated as auxiliaries.

The scrubber will be located on the roof of the existing facility. A 60 ft. square area is available for new equipment next to the asphalt saturator vent stack. A four inch concrete slab covers the area. All utilities are available at the site. The sewer is available and will accept water in the 4 to 10 pH range, if it contains less than 1 wt % solids content.

Neither the cost of borax to be used in buffering nor the cost of neutralization of hydroxide ion prior to discharge has been included.

TABLE 80

SCRUBBER OPERATING CONDITIONS

FOR ASPHALT SATURATOR SPECIFICATION

Size	Small	Large
Process Conditions		
Gas Rate, ACFM	22,600	52,800
Gas Temp., °F	140	100
Gas Rate, SCFM	20,000	50,000
Moisture Content, vol %	4.0	1.6
Hcbn Emission Rate, lb/hr	50	50
Gas from Scrubber		
Gas Rate, ACFM	21,300	50,500
Gas Temp., °F*	95	70
Gas Rate, SCFM	20,300	50,500
Moisture Content, vol %*	5.2	2.5
Gas Rate, DSCFM	19,200	49,200
Hcbn Content, lb/hr	8	8
Hcbn Removal Eff., wt %	84	84

*Supplied by bidder

TABLE 81

ESTIMATED CAPITAL COST DATA (COSTS IN DOLLARS) FOR WET SCRUBBERS FOR ASPHALT SATURATOR

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			22,600	52,800
°F			140	100
SCFM			20,000	50,000
Moisture Content, Vol. %			4.0	1.6
Effluent Contaminant Loading lb/hr			50	50
Cleaned Gas Flow				
ACFM			21,300	50,500
°F			95	70
SCFM			20,300	50,500
Moisture Content, Vol. %			5.2	2.5
Cleaned Gas Contaminant Loading lb/hr			8	8
Cleaning Efficiency, %			84	84
(1) Gas Cleaning Device Cost			12,787	26,325
(2) Auxiliaries Cost				
(a) Fan(s)			7,670	17,582
(b) Pump(s)			1,418	1,711
(c) Damper(s)				
(d) Conditioning, Equipment			8,120	8,120
(e) Dust Disposal Equipment			4,661	6,795
(3) Installation Cost				
(a) Engineering			15,000	20,000
(b) Foundations & Support Ductwork Stack Electrical Piping Insulation Painting			35,000	40,000
Supervision Startup			1,000	1,000
Performance Test Other			3,000	3,000
(4) Total Cost			88,656	124,533

FIGURE 52

CAPITAL COST OF WET SCRUBBERS FOR ASPHALT SATURATOR

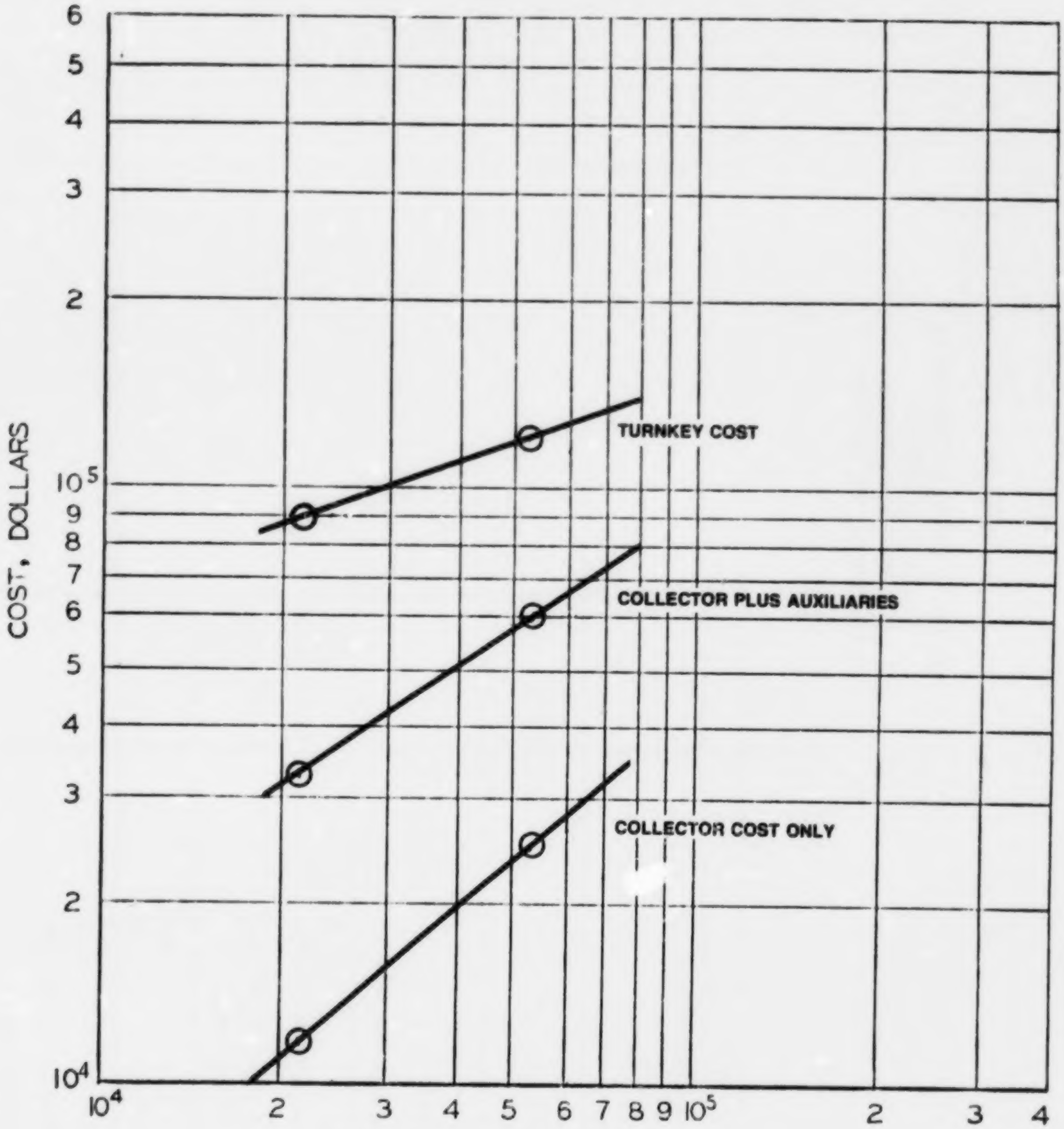


TABLE 82

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS
FOR ASPHALT SATURATOR

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 2,000					
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor	$6/hr.			1,200	1,200
Materials					
Total Maintenance				1,200	1,200
Replacement Parts				100	100
Total Replacement Parts				100	100
Utilities					
Electric Power	$0.011/kwh			1,746	3,492
Fuel					
Water (Process)	$0.25/MGal			6,000	13,500
Water (Cooling)					
Chemicals, Specify- Permanganate	$0.50/lb			1,276,000	1,276,000
Total Utilities				1,283,746	1,292,992
Total Direct Cost				1,285,046	1,294,292
Annualized Capital Charges	16% of Cap			14,185	19,925
Total Annual Cost				1,299,231	1,314,217

FIGURE 53

ANNUAL COST OF WET SCRUBBERS FOR ASPHALT SATURATOR

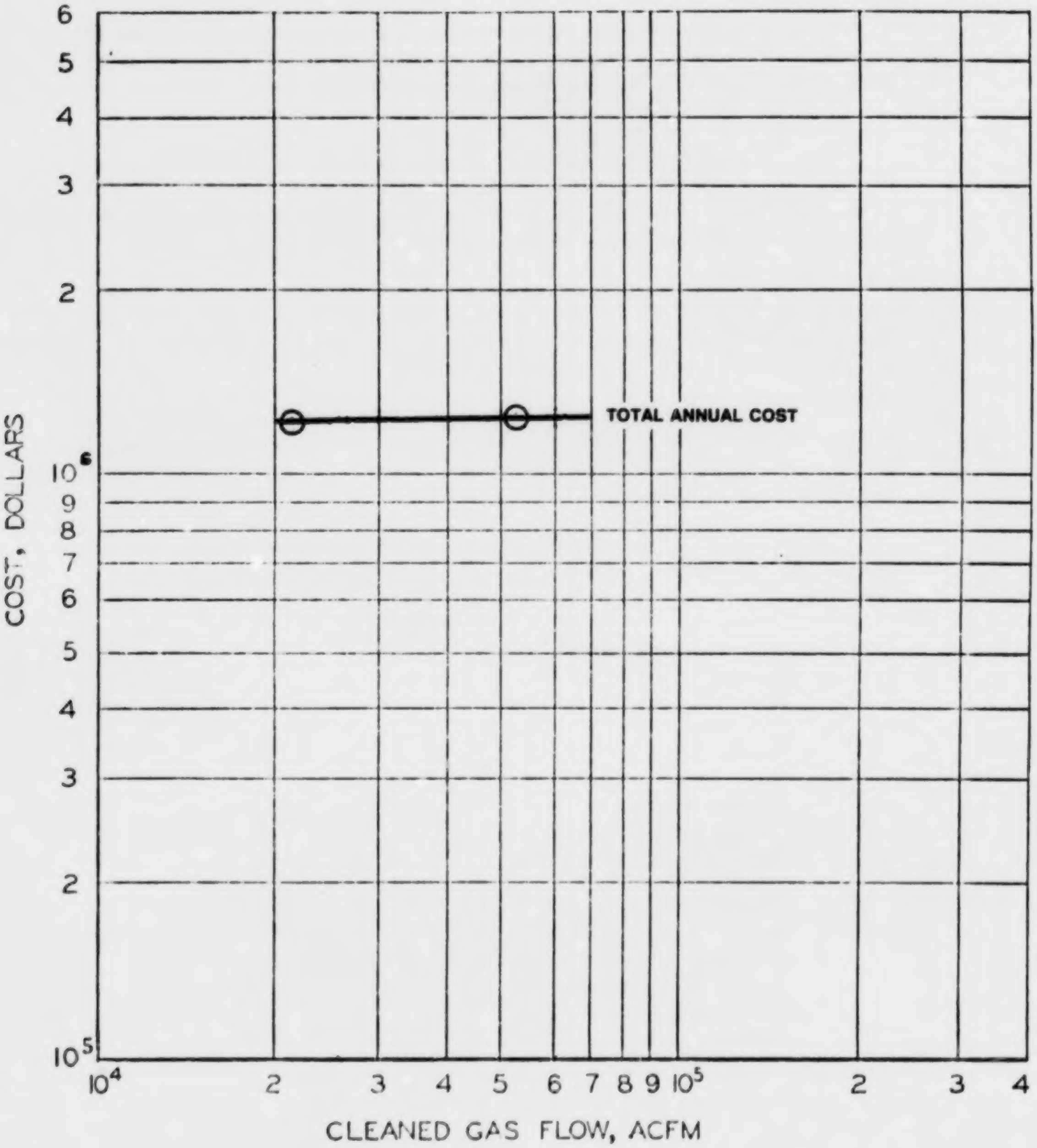


TABLE 83

THERMAL INCINERATOR PROCESS DESCRIPTION

FOR ASPHALT SATURATOR SPECIFICATION
(With Heat Exchange)

This specification describes the requirements of a thermal combustion system for the abatement of hydrocarbon emissions from an asphalt saturator. Processing conditions and specifications for small and large facilities are tabulated in Table 49.

The incinerator will be gas fired using natural gas available at a pressure of 1.0 psig, having a specific gravity of 0.6 and an upper heating value of 1,040 BTU/SCF. The exhaust gas from the saturator will contain sufficient oxygen to allow firing of the burner without the addition of a combustion air system.

A fan equipped with a V-belt drive will be required at the incinerator inlet. The fan will have the capacity to overcome the pressure drop of the ductwork, burner, and heat exchanger. The ductwork of the system will be sized for a maximum ΔP of 2 in. w.c. (hot).

The heat exchanger will be a counterflow shell and tube exchanger and be designed to operate at an incinerator outlet temperature of 1500°F. The maximum exchanger pressure drop (shell side and tube side) will not exceed 6.0 in. w.c. The contaminated gas will flow through the tube side.

The incinerator will be supplied with a suitable control panel. All equipment will be designed for outdoor operation and to meet the Factory Insurance Association's standards.

The cost estimate will include the following items:

- *Incinerator*
- *Burner*
- *10 Ft. Stack*
- *Controls*
- *Control Panel*
- *Structural Steel*
- *Fuel Gas Piping*
- *Electrical*
- *Ductwork*
- *Insulation*
- *Fan*
- *Fan Motor*
- *Two-day Start-up Service*
- *Heat Exchanger*
- *Dampers*

All items, with the exception of the incinerator, burner, and heat exchanger, will be considered auxiliaries. Vendors quotations should include both price information and the design information requested in the operating conditions section.

The incinerator will be located on the roof of the existing facility, and no modification of the building structure is required. The duct run from the asphalt saturator to the incinerator will be 80 ft. All utilities are available within 30 ft. of the control cabinet, motor, and burner.

TABLE 84

THERMAL INCINERATOR OPERATING CONDITIONS

FOR ASPHALT SATURATOR SPECIFICATION
(With Heat Exchange)

Plant Size	*Small*	*Large*
Process Conditions		
Gas Rate, ACFM	22,600	52,800
Gas Temperature, °F	140	100
Gas Rate, SCFM	20,000	50,000
Hcbn Emission Rate, lb/hr	50	50
Heating Value of Gas, BTU/SCF	0.8	0.3
Heat of Combustion of Hcbn, BTU/lb	18,000	18,000
Incinerator Specifications		
Residence Time @ Temperature, sec.	0.3	0.3
Inlet Tubeside Temperature, °F	140	100
*Incinerator Outlet Temperature, °F**	678	657
*Incinerator Inlet Temperature, °F**	991	974
*Burner ΔT from Fuel Gas, °F**	484	511
*Burner ΔT from Flame Combustion, °F***	3	1.5
*Burner Outlet Temperature, °F**	1,487	1,495
*Unit ΔT from Thermal Combustion, °F**	22	13.5
*Burner Duty, mm BTU/hr**	12.6	33.2
*H.E. Duty mm BTU/hr**	19.4	49.6
Thermal Efficiency Counterflow H.E., %	60	60
*Overall Heat Transfer Coef, U**	5.4	5.5
*Tube Surface Area, Ft²**	7,549	18,332
Case 1 – Medium Efficiency		
Hcbn Emission Rate, lb/hr	1	1
Efficiency, wt %	98	98
Case 2 – High Efficiency		
Hcbn Emission rate, lb/hr	0.5	0.5
Efficiency, wt %	99	99

**Supplied by bidder.*

***Assuming 10% conversion of fume in the flame*

TABLE 85

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR THERMAL INCINERATORS (WITH HEAT EXCHANGE)
FOR ASPHALT SATURATOR

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	22,600	52,800	22,600	52,800
°F	140	100	140	100
SCFM	20,000	50,000	20,000	50,000
Moisture Content, Vol. %				
Effluent Contaminant Loading				
lb/hr	50	50	50	50
Cleaned Gas Flow				
ACFM				
°F	678	657	678	657
SCFM				
Moisture Content, Vol. %				
Cleaned Gas Contaminant Loading				
lb/hr	1	1	.5	.5
Cleaning Efficiency, %	98	98	99	99
(1) Gas Cleaning Device Cost	Same As High Efficiency	Same As High Efficiency	120,775	269,850
(2) Auxiliaries Cost			9,565	19,845
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering			5,900	12,600
(b) Foundations & Support Ductwork Stack Electrical Piping Insulation Painting Supervision Startup Performance Test Other			88,725	130,435
(4) Total Cost			224,965	432,730

FIGURE 54

CAPITAL COST OF THERMAL INCINERATORS (WITH HEAT EXCHANGE) FOR ASPHALT SATURATOR

(High Efficiency)

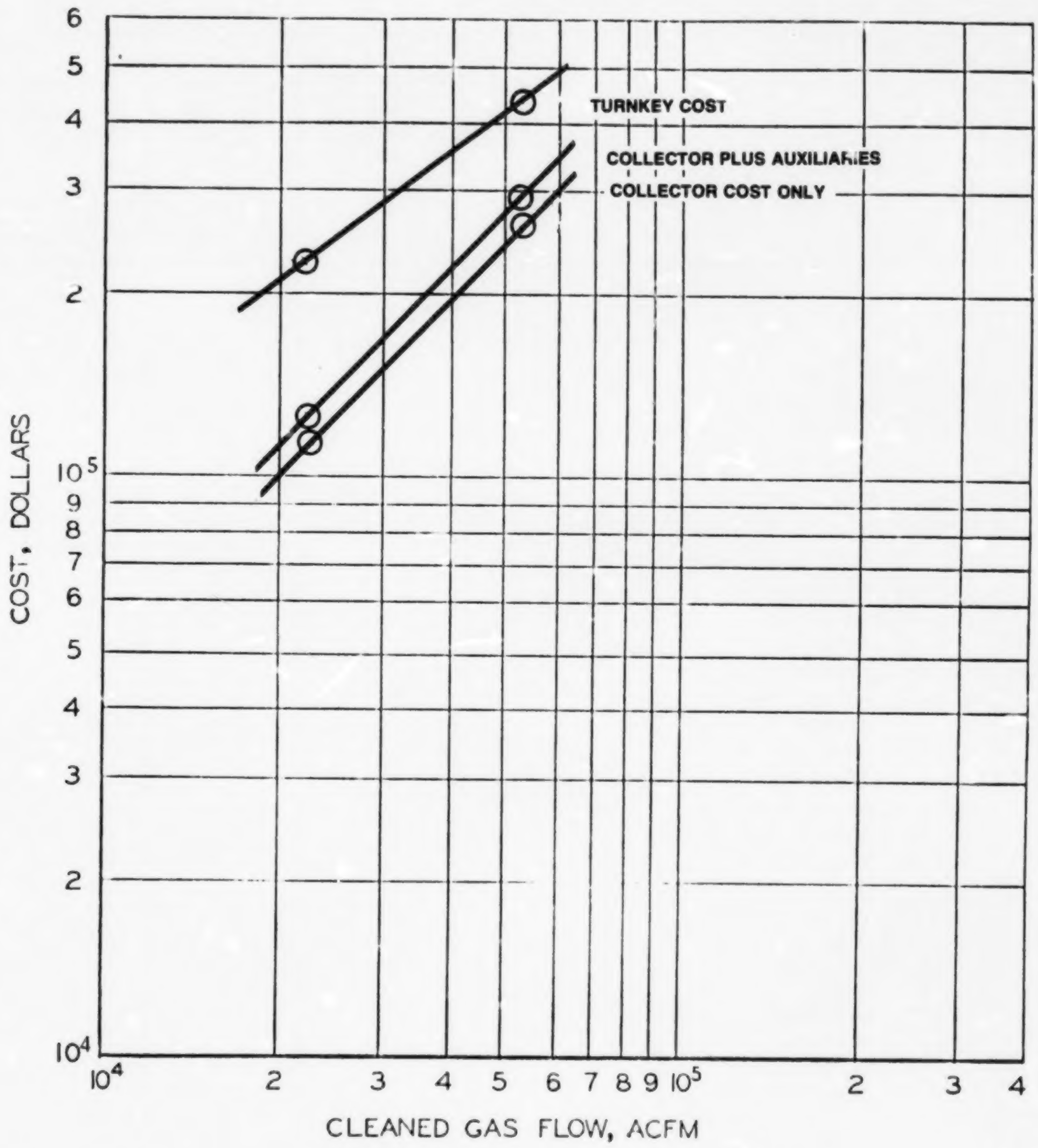


TABLE 86

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR THERMAL INCINERATORS (WITH HEAT EXCHANGE)
FOR ASPHALT SATURATOR

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 2,000					
Operating Labor (if any)					
Operator					
Supervisor	$8/hr.	1,280	1,920	1,280	1,920
Total Operating Labor		1,280	1,920	1,280	1,920
Maintenance					
Labor	$6/hr.	240	480	240	480
Materials		400	1,100	400	1,100
Total Maintenance		640	1,580	640	1,580
Replacement Parts		150	350	150	350
Total Replacement Parts		150	350	150	350
Utilities					
Electric Power	$0.011/kwh	1,243	2,970	1,243	2,970
Fuel	$0.7232/ 1000 ft^3	20,144	53,184	20,160	53,200
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities		21,387	56,154	21,403	56,170
Total Direct Cost		23,457	60,004	23,473	60,020
Annualized Capital Charges	16% of Cap	35,994	69,237	35,994	69,237
Total Annual Cost		59,451	129,241	59,467	129,257

FIGURE 55

ANNUAL COST OF THERMAL INCINERATORS (WITH HEAT EXCHANGE) FOR ASPHALT SATURATOR
(High Efficiency)

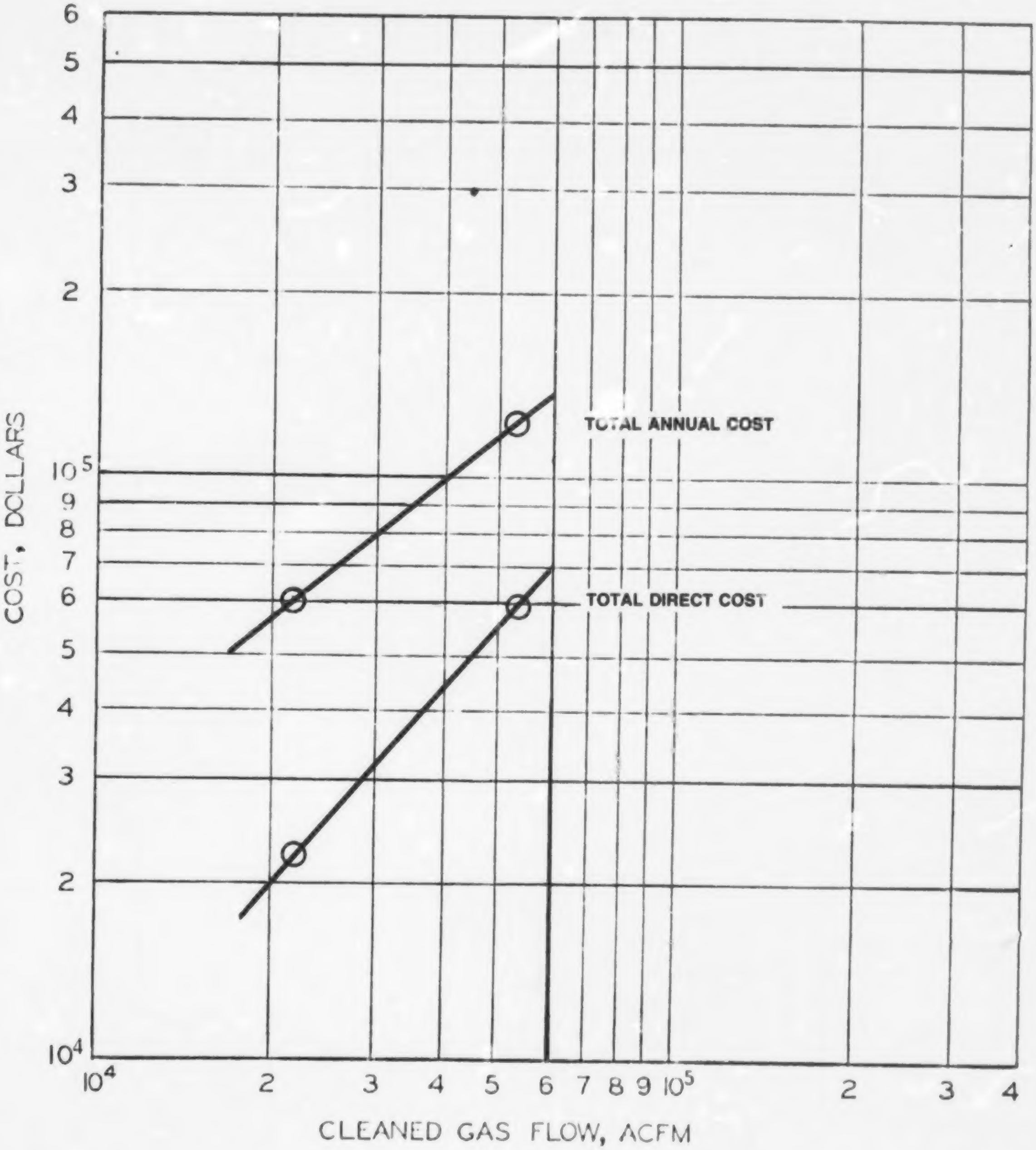


TABLE 87

GLASS FIBER MAT FILTER PROCESS DESCRIPTION

FOR ASPHALT SATURATOR SPECIFICATION

A glass fiber mat filter is to control hydrocarbon emissions from an asphalt saturator. Processing conditions and specifications are tabulated in Table 53. Bids should include the following items:

1. *Filter unit*
2. *Necessary fans and motors*
3. *Twenty foot stack*
4. *Interconnecting ductwork for all equipment furnished*
5. *Appropriate control system*

All of the above, except the filter should be treated as auxiliaries.

The filter will be located on the roof of the existing facility. A 60 ft. square area is available for new equipment next to the asphalt saturator vent stack. A four inch concrete slab covers the area. All necessary utilities are available at the site.

Vendor's quotation should include total price information and relevant design information, including the expected pressure drop across the unit at the required efficiency levels. Vendor should also specify the pressure drop which would be required to achieve 99 wt % collection efficiency, but need not supply price information for these extra cases.

TABLE 88

GLASS FIBER MAT FILTER OPERATING CONDITIONS FOR ASPHALT SATURATOR SPECIFICATION

Size	Small	Large
Process Conditions		
Gas Rate, ACFM	22,600	52,800
Gas Temp., °F	140	100
Gas Rate, SCFM	20,000	50,000
Moisture Content, vol %	4.0	1.6
Hcbn Emission Rate, lb/hr	50	50
Medium Efficiency Case		
Outlet Gas Rate, SCFM	20,000	50,000
Outlet Hcbn Rate, lb/hr	1	1
ΔP Across Filter, in. w.c.*	26	26
Collection Efficiency, wt %	98	98
High Efficiency Case		
Outlet Gas Rate, SCFM	20,000	50,000
Outlet Hcbn Rate, lb/hr	0.5	0.5
ΔP Across Filter, in. w.c.*	28-30	28-30
Collection Efficiency, wt %	99	99

*Supplied by bidder.

TABLE 89

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR GLASS FIBER MAT FILTERS FOR ASPHALT SATURATOR

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	22,600	52,800		
°F	140	100		
SCFM	20,000	50,000		
Moisture Content, Vol. %	4.0	1.6		
Effluent Contaminant Loading				
lb/hr	50	50		
Cleaned Gas Flow				
ACFM	22,600	52,800		
°F	140	100		
SCFM	20,000	50,000		
Moisture Content, Vol. %	4.0	1.6		
Cleaned Gas Contaminant Loading				
lb/hr	1	1		
Cleaning Efficiency, %	98	98		
(1) Gas Cleaning Device Cost Fans and Startup Incl.	62,750	108,650		
(2) Auxiliaries Cost				
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)	2,800	6,900		
(d) Conditioning, Equipment	12,750	25,500		
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering	25,000	40,000		
(b) Foundations & Support Ductwork Stack Electrical Piping Insulation Painting	125,000	155,000		
Supervision	18,000	18,000		
Startup				
Performance Test				
Other				
(4) Total Cost	246,300	354,050		

FIGURE 56

CAPITAL COST OF HIGH ENERGY AIR FILTERS FOR ASPHALT SATURATOR

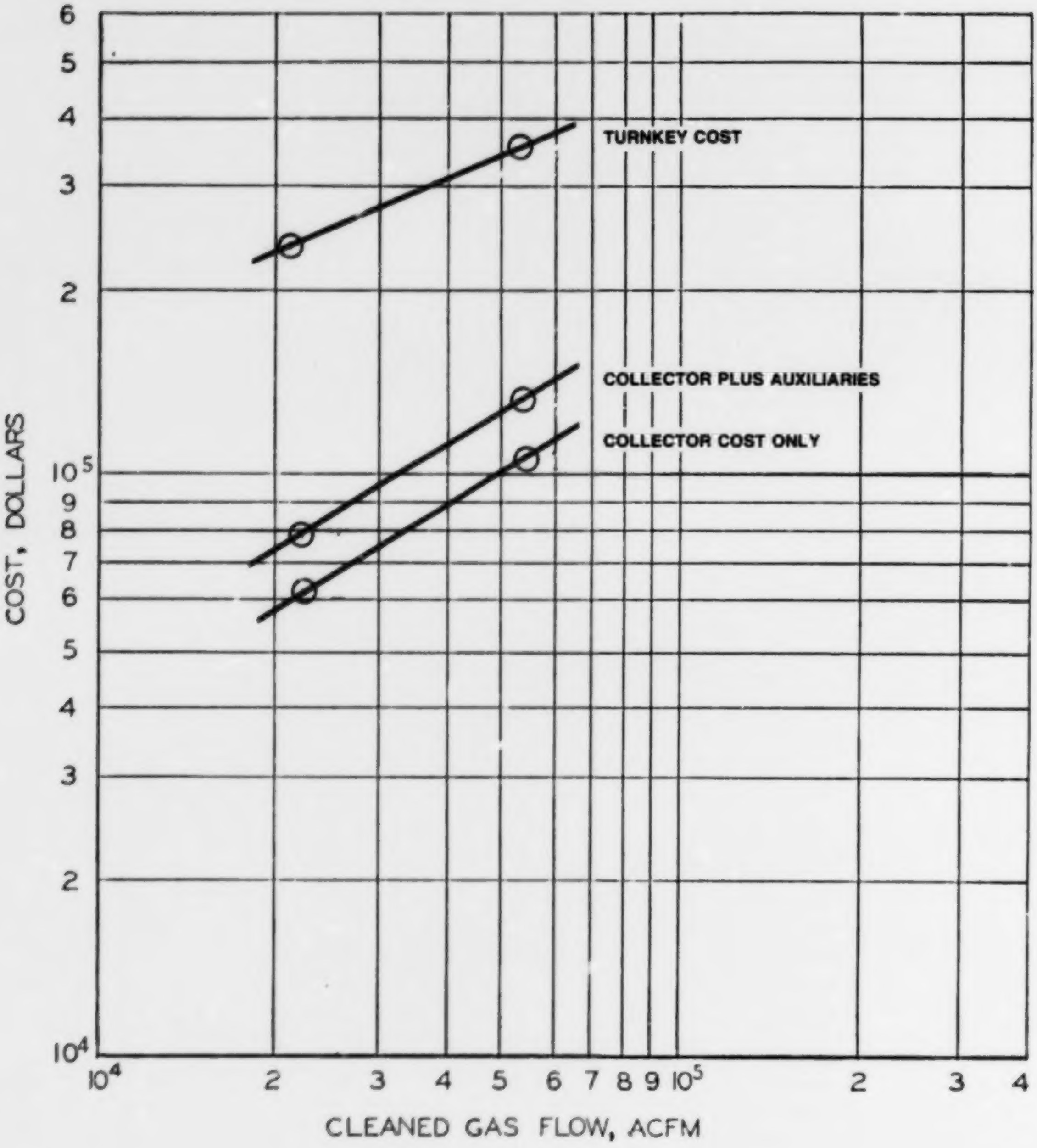


TABLE 90

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR GLASS FIBER MAT FILTERS
FOR ASPHALT SATURATOR

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 2,000					
Operating Labor (if any)					
Operator	$6/hr.	100	100		
Supervisor					
Total Operating Labor		100	100		
Maintenance					
Labor	$6/hr.	300	300		
Materials		500	500		
Total Maintenance		800	800		
Replacement Parts		3,500	7,500		
Total Replacement Parts		3,500	7,500		
Utilities					
Electric Power	$0.011/kwh	3,237	7,547		
Fuel					
Water (Process)					
Water (Cooling)	$0.05/MGal	42	168		
Chemicals, Specify					
Total Utilities		3,279	7,715		
Total Direct Cost		7,379	16,115		
Annualized Capital Charges	16% of Cap	39,408	55,648		
Total Annual Cost		46,787	71,763		

FIGURE 57

ANNUAL COST OF HIGH ENERGY AIR FILTERS FOR ASPHALT SATURATOR

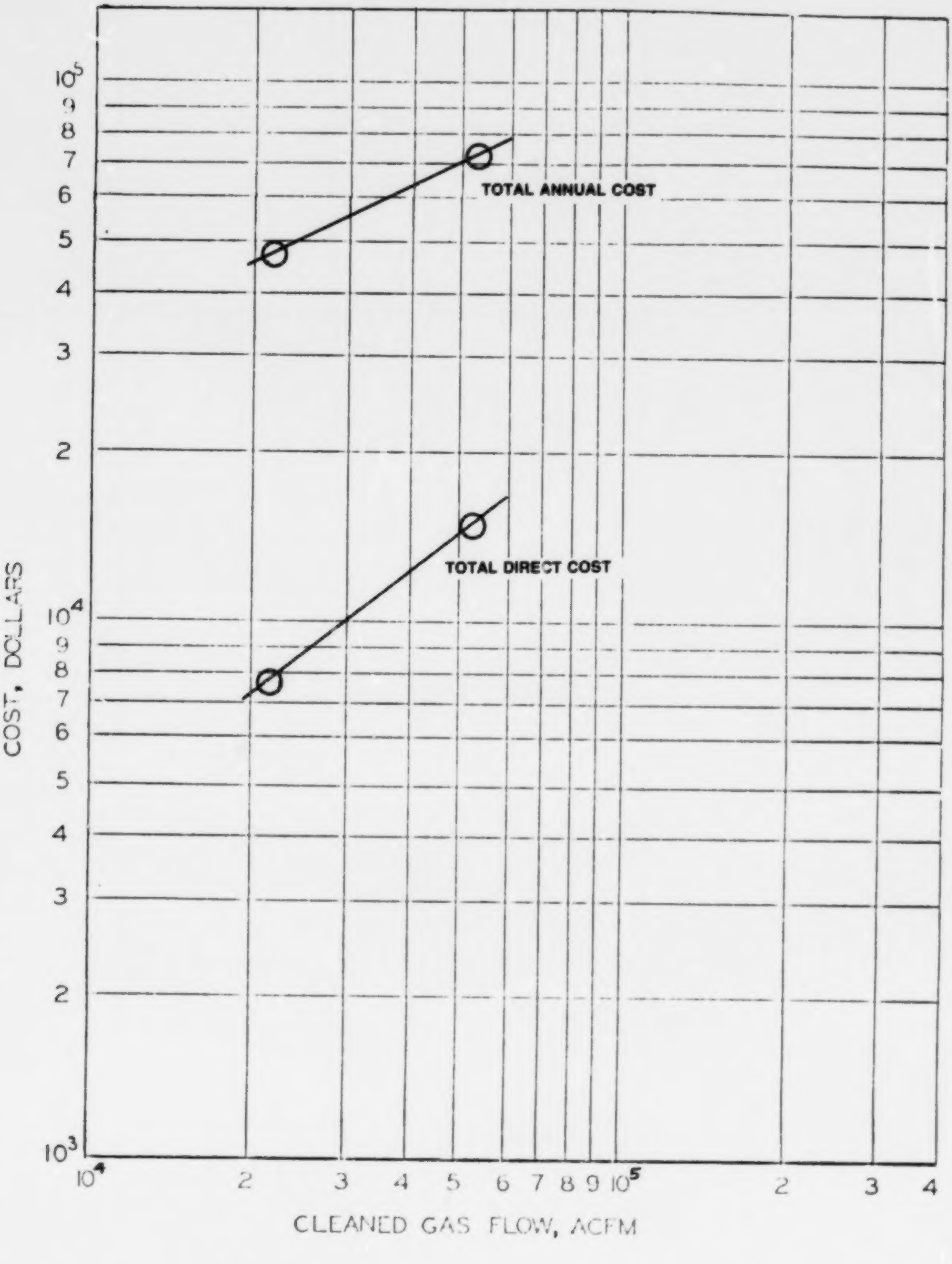


TABLE 91

THERMAL INCINERATOR PROCESS DESCRIPTION

FOR ASPHALT BLOW STILL
(With Heat Exchange)

This specification describes the requirements of a thermal combustion system for the abatement of hydrocarbon emissions from an asphalt blow still. Processing conditions and specifications for small and large facilities are tabulated in Table 57.

The incinerator will be gas fired using natural gas available at a pressure of 1.0 psig, having a specific gravity of 0.6 and an upper heating value of 1,040 BTU/SCF. The exhaust gas from the blow still will contain sufficient oxygen to allow firing of the burner without the addition of a combustion air system.

A fan equipped with a V-belt drive will be required at the incinerator inlet. The fan will have the capacity to overcome the pressure drop of the ductwork, burner, and heat exchanger. The ductwork of the system will be sized for a maximum ΔP *of 2 in. w.c. (hot).*

The heat exchanger will be a counterflow shell and tube exchanger and be designed to operate at an outlet incinerator temperature of 1500°F. The maximum exchanger pressure drop (shell side and tube side) will not exceed 6.0 in. w.c. The contaminated gas will flow through the tube side.

The incinerator will be supplied with a suitable control panel. All equipment will be designed for outdoor operation and to meet the Factory Insurance Association's standards.

The cost estimate will include the following items:

Incinerator
Burner
10 Ft. Stack
Controls
Control Panel
Structural Steel
Fuel Gas Piping
Electrical
Ductwork
Insulation
Fan
Fan Motor
Two-day Start-up Service
Heat Exchanger
Dampers

All items, with the exception of the incinerator, burner, and heat exchanger, will *be considered auxiliaries. Vendors quotations should include both price information and the design information requested in the operating conditions section.*

The incinerator will be located on the roof of the existing facility, and no modification of the building structure is required. The duct run from the asphalt blow still to the incinerator will be 200 ft. All utilities are available within 30 ft. of the control cabinet, motor, and burner.

TABLE 92

THERMAL INCINERATOR OPERATING CONDITIONS

FOR ASPHALT BLOW STILL SPECIFICATION
(With Heat Exchange)

Plant Size	*Small*	*Large*
Process Conditions		
Gas Rate, ACFM	*10,600*	*34,100*
Gas Temperature, °F	*210*	*210*
Gas Rate, SCFM	*8,400*	*27,000*
Hcbn Emission Rate, lb/hr	*52*	*168*
Heating Value of Gas, BTU/SCF	*1.9*	*1.9*
Heat of Combustion of Hcbn, BTU/lb	*18,000*	*18,000*
Incinerator Specifications		
Residence Time @ Temperature, sec.	*0.3*	*0.3*
Inlet Tubeside Temperature, °F	*210*	*210*
*Incinerator Outlet Temperature, °F**	*720*	*723*
*Incinerator Inlet Temperature, °F**	*1,016*	*1,013*
*Burner ΔT from Fuel Gas, °F**	*422*	*426*
*Burner ΔT from Flame Combustion, °F***	*5.5*	*5.5*
*Burner Outlet Temperature, °F**	*1,468*	*1,468*
*Unit ΔT from Thermal Combustion, °F**	*56.5*	*56.5*
*Burner Duty, mm BTU/hr**	*4.6*	*14.9*
*H.E. Duty mm BTU/hr**	*7.7*	*24.7*
*Thermal Efficiency Counterflow, H.E., %****	*60 (65)*	*60 (64.5)*
*Overall Heat Transfer Coef, U**	*5.4*	*5.8*
*Tube Surface Area, ft²**	*3,138*	*9,589*
	Case 1 – High Efficiency	
Hcbn Emission Rate, lb/hr	*0.5*	*0.5*
Efficiency, wt %	*99*	*99*

**Supplied by bidder.*
***Assuming 10% conversion of fume in the flame*
****One bidder reported higher thermal efficiency counterflow percentages (shown in parenthesis) than those specified.*

TABLE 93

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR THERMAL INCINERATORS
FOR ASPHALT BLOW STILL

	Medium Efficiency		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			10,600	34,100
°F			210	210
SCFM			8,400	27,000
Moisture Content, Vol. %				
Effluent Contaminant Loading				
lb/hr			52	52
Cleaned Gas Flow				
ACFM				
°F			720	720
SCFM				
Moisture Content, Vol. %				
Cleaned Gas Contaminant Loading				
lb/hr			.5	.5
Cleaning Efficiency, %			99	99
(1) Gas Cleaning Device Cost			67,175	147,350
(2) Auxiliaries Cost			4,599	13,250
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering			4,300	8,800
(b) Foundations & Support			61,200	95,275
Ductwork				
Stack				
Electrical				
Piping				
Insulation				
Painting				
Supervision				
Startup				
Performance Test				
Other				
(4) Total Cost			137,274	264,675

FIGURE 58

CAPITAL COST OF THERMAL INCINERATORS FOR ASPHALT BLOW STILL

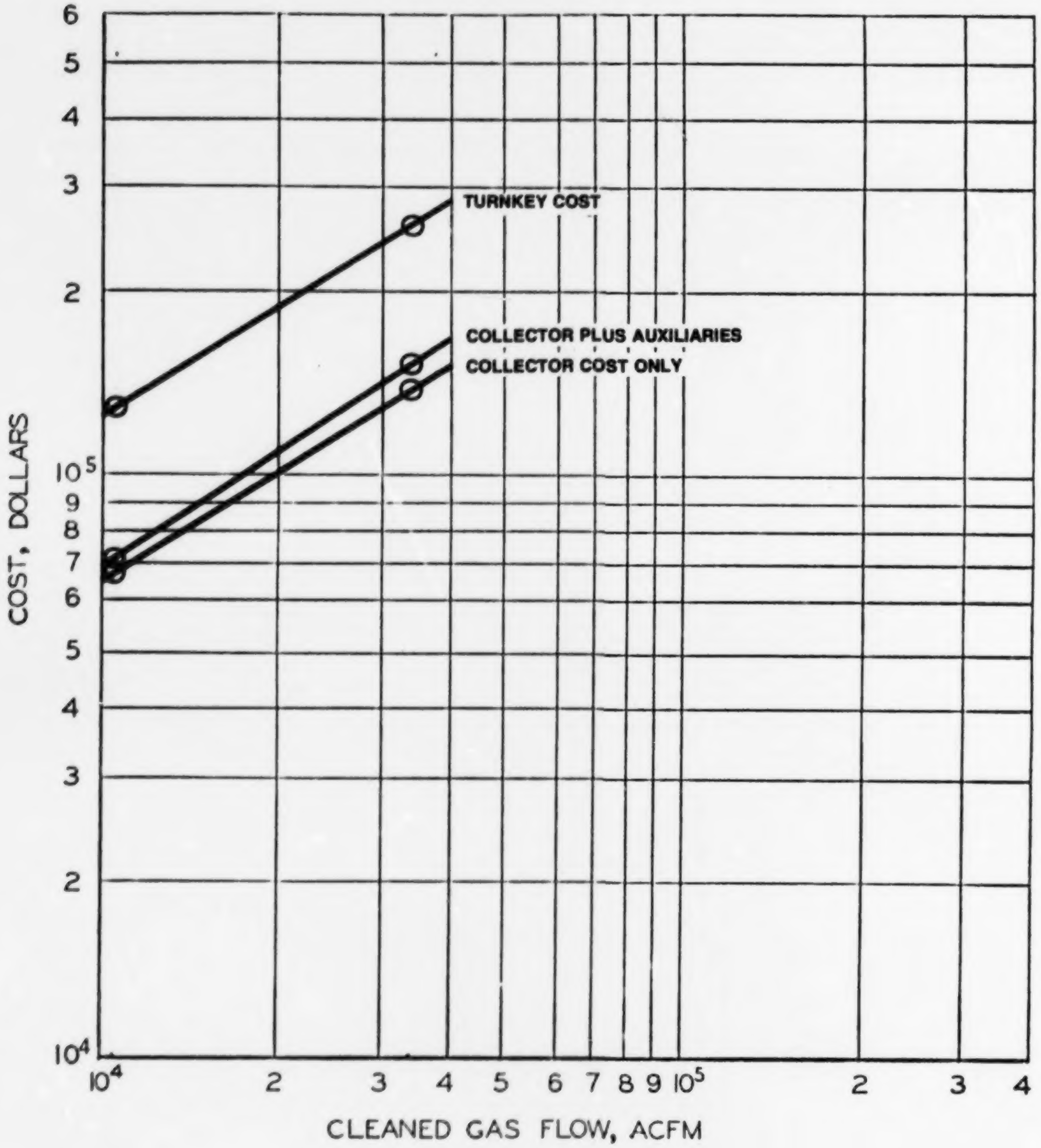


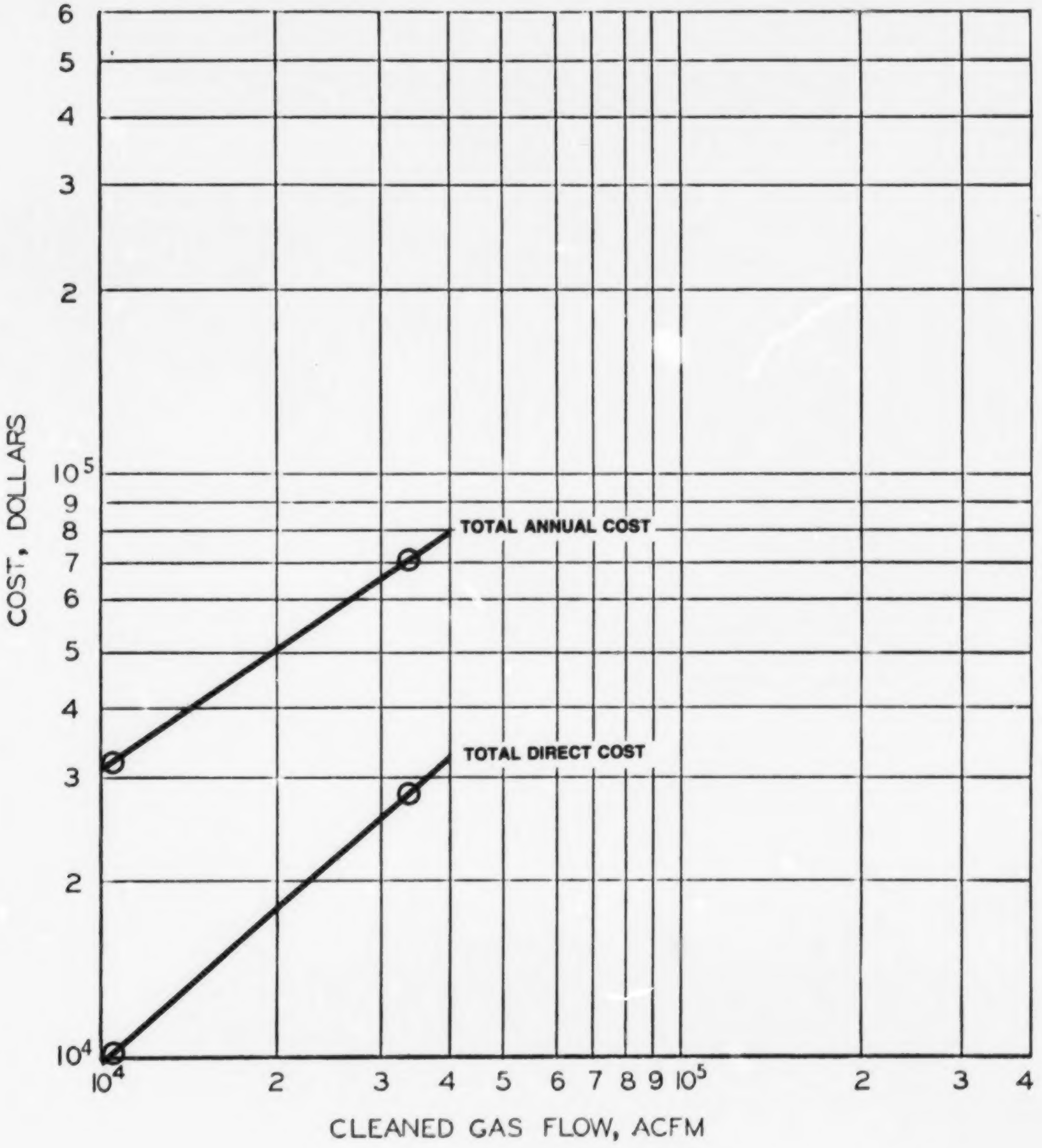
TABLE 94

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR THERMAL INCINERATORS
FOR ASPHALT BLOW STILL

Operating Cost Item	Unit Cost	Medium Efficiency		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year 2,000					
Operating Labor (if any)					
Operator					
Supervisor	$8/hr.			1,280	1,280
Total Operating Labor				1,280	1,280
Maintenance					
Labor	$6/hr.			240	240
Materials				400	600
Total Maintenance				640	840
Replacement Parts				150	200
Total Replacement Parts				150	200
Utilities					
Electric Power	$0.011/kwh			781	2,497
Fuel	$0.7232/ 1000 ft^3			7,360	23,880
Water (Process)					
Water (Cooling)					
Chemicals, Specify					
Total Utilities				8,141	26,377
Total Direct Cost				10,211	28,697
Annualized Capital Charges	16% of Cap			21,964	42,348
Total Annual Cost				32,175	71,045

FIGURE 59

ANNUAL COST OF THERMAL INCINERATORS FOR ASPHALT BLOW STILL



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2. Air Pollution Engineering Manual, U.S. Dept. of Health Education and Welfare, Public Health Services Publication No. 999-AP-40, Cincinnati, Ohio, 1967.

3. Goldfield, J.; Gandhi, K.; "Glass Fiber Mats to Reduce Effluents from Industrial Processes," Journal of the Air Pollution Control Association, July, 1970, Vol. 20, No. 7, pp. 466-469.

7. SURFACE COATING OPERATIONS

The term "surface coatings" applies to a great many different coating materials, both organic and inorganic, and different application technologies. The air pollution control problems which accompany each type of coating and application method are correspondingly different from one another. This discussion has been limited, by the scope of the contract under which it was prepared, to organic coatings and application technologies which involve solvent evaporation or other vapor phase organic emission.

The basic purpose of an organic coating is to form a film over a substrate which will cohere to itself and adhere to the surface over which it is applied. In current times, the usefulness of organic coatings has been widely extended from simply a protective (weather and corrosion) function to diverse applications which include:

1. Electrical insulation
2. Lubricity
3. Temperature control
4. Fire retardency
5. Control of marine fouling
6. Sound deadening

Currently, most organic coatings are formulated with synthetic resins which can be tailored to solve a particular finishing problem. They can be applied to a surface by a number of operations including dipping, spraying, flow-coating, and roller coating. Furthermore, combinations of these operations, each designed for a specific task, are found.

SCIENTIFIC PRINCIPLES OF COATING FORMATION

The surface coating process consists of the conversion of the solutions or melts of film-formers to the amorphous state and the fixation of the film as it is formed to a particular substrate.

Film-formers may be classified into those which transform during the coating operation and those which do not transform.

Formation of Non-Transforming Coatings

The theory of the mechanism of film-forming for these materials, which include cellulose esters, perchlorvinylic types, and many others, states that when solvent is evaporated from solutions of compounds of low molecular weight resins, the film-formers are converted to the amorphous state. The conditions for pure solvent evaporation must be differentiated from those for solvent evaporation from solutions, particularly from solutions of high molecular weight compounds. For lacquers, the evaporation rate may be given as:

$$g = \Sigma g_o x \qquad (\text{grams/m}^2\text{/min})^1 \qquad (1)$$

where g_o is the evaporation rate for an individual constituent and x is the mole fraction of that constituent in the original solution.

Empirical evidence indicates, for the majority of solvents, the evaporation of the first 90 percent can be expressed by

$$L = ct^m \qquad (2)$$

where L is the percent of solvent lost, c and m are constants that are characteristic of the solvent, and t is the time. The remaining 10% evaporates slowly, and its evaporation does not obey the above equation. Pigments have different effects on evaporation rates. Coarse-particle pigments will accelerate evaporation, whereas finely dispersed pigments retard it.

Coatings Formed by Transformation

The transformation of monomers or linear polymers to three-dimensional polymers usually takes place as a result of the following processes:

1. Polycondensation (in phenol-aldehyde resins, and for coatings dried by heat).
2. Polymerization or copolymerization at the sites of unsaturated bonds, either directly or through the agency of oxygen.

Many film-forming substances will transform as a result of both of these processes.

PROCESS DESCRIPTION

There are several common methods by which surface coatings are applied: dipping, spraying, flow coating, and roller coating. In modern industry, these methods are applied to a large number of different types of coating materials, such as those listed on Table 95. Some of these processes, such as dipping and flow coating, have become obsolete in some industries as newer, inorganic systems are developed.

TABLE 95

EXAMPLES OF SURFACE-COATING FORMULAS ON AN AS-PURCHASED BASiS

Type of Surface Coating	Non-Volatile Portion	Hydrocarbons Aliphatic	Aromatic	Alcohol	Ketones	Esters & Ethers
Paint	44	56	—	—	—	—
Varnish	50	45	5	—	—	—
Enamel	58	10	30	2	—	—
Lacquer	23	7	30	9	22	9
Metal Primer	34	33	33	—	—	—
Glaze	80	—	20	—	—	—
Resin*	50	—	—	—	—	—
Sealer	50	40	—	—	—	—
Shellac	50	—	—	50	—	10
Stain	20	—	80	—	—	—
Zinc Chromate	60	—	40	—	—	—

*Contains 50% solvent of an unspecified type.

Paint Dip Tanks

In this method of application, an object is immersed in a simple paint container and then removed. These containers frequently have conical bottoms. The excess paint is drained from the object back to the dip tank, either by simply suspending the object over the container or by using drainboards that drain back to the dip tank. Agitation is necessary in order to keep the paint mixture uniform. The most common agitation method consists of pumping paint from the bottom of the tank to some point near the tank top, but still under the liquid surface.

Flow Coating Machines

Flow coating consists of flowing paints in a steady stream over objects that are suspended from a conveyor line. The paint is recirculated by a pump from a drain basin back to the paint nozzles.

Roller Coating Machines

Paint roller coating machines usually have three or more power-driven rollers and are quite similar to printing presses in their construction. Paint is transferred from the first roll, which is partially immersed in the paint, to a second roll which is running parallel to it. The sheet work to be coated is run between the second and third roll and is coated by transfer of paint from the second roll. The quantity of paint applied is determined by the distance between the rolls through which the sheet passes.

Spraying

In spraying operations, a spray gun usually operated by compressed air, is used to spray the paint on the object to be painted. In order to insure that an explosive concentration of solvent vapor does not occur and to protect the health of the spray gun operator, a booth or enclosure ventillated by a fan provides a means of ventilating the spray area. Table 96 shows threshold limit values of typical paint solvents. These values are average concentrations to which workers may be safely exposed for an 8-hour day without adverse effect on their health.

The spray booth may also be equipped to filter incoming air as well as remove particulate matter from the exhausted air.

TABLE 96

LIMITING VALUES OF TYPICAL PAINT SOLVENTS

	Lower Explosive Limit (LEL)* %	25% LEL ppm	Worker Threshold Limit Values** ppm
Acetone	2.15	5,400	1,000
Amyl Acetate	1.1	2,750	200
Methyl Ethyl Ketone	1.81	4,525	250
Butyl Acetate	1.7	4,250	200
Cellosolve	2.6	6,500	200
Cellosolve Acetate	1.71	4,275	100
Ethyl Acetate	2.18	5,450	400
Ethanol	3.28	8,200	1,000
Naphtha (Petroleum)	0.92 to 1.1	2,300	500
Toluene	1.27	3,175	200
Xylene	1.0	2,500	200
Mineral Spirits	0.77	1,925	500

*Adapted from: Factory Mutual Engineering Division, Handbook of Industrial Loss Prevention, McGraw Hill Book Co., Inc. NY, 1959.

**Adapted from: American Medical Association Archives of Environmental Health, 14:186-89, 1956.

The chief advantages of spray painting are the speed of painting and the comparative ease of obtaining a relatively smooth finish; the chief disadvantage is the waste of material that can occur. A considerable quantity of particulate matter results from the use of the common air atomization type spray gun. A 60 percent overspray of an object is quite common. Particulate matter in paint spray booths is controlled by baffle plates, filter pads, or water spray curtains.

The discharge from spray booth operations consists of particulate matter and organic-solvent vapors. The particulate matter concentration seldom exceeds 0.01 grain per SCF of unfiltered exhaust. The location of the exhaust stack is extremely important so that paint spotting on neighboring property is avoided. The solvent concentration in spray booth effluent varies from 100 to 200 ppm. Depending on the extent of operation, the solvent emission out of the spray booth stack will vary from less than 1 pound per day to 3,000 pounds per day. Solvent vapors will take part in photochemical smog reactions leading to products that result in eye irritation. Odors also cause local nuisances.

TYPES OF SPRAY BOOTHS

Dry Type Booths

Dry Baffle Spray Booths

This type of booth is especially suitable for spraying small objects which are manually loaded and unloaded through the front opening. Overspray adheres to the face of baffles or is trapped in eddies of air striking the rear surface of baffles. The auxiliary equipment would consist of an exhaust fan with electric motor, light fixtures and the exhaust chamber.

Paint Arrester Type

This is similar to the dry baffle type except that air-borne paint particles from exhaust air are removed by means of disposable filters. This unit is used mainly for intermittent spray operations; such as, refinish shops, schools, and production lines where paint consumption is moderate.

Dispo Spray Booths

In the "dispo" type of booth, maintenance and cleaning time are reduced to a minimum. The booth may be used for heavy or light production spray operations.

The entire back-end of the booth is covered with a felt material that collects over-spray and particles as the exhaust air is drawn through it. As the filtering media becomes loaded with overspray and the differential in static pressure rises to a preset point, fresh media is rolled down by a power drive. The usage of filter media is directly proportional to paint load. Auxiliaries include the customary exhaust fan, lighting, filter media, and exhaust duct components.

Water Wash Spray Booths

These are the most widely used and most versatile type of booth. One of the primary benefits of this type of booth is that when articles being sprayed are of convenient size (up to and including motor vehicle bodies) the booths will permit spraying to be conducted in the same workshop as other operations of both a mechanical and finishing nature.

The main feature of this type of booth is a powerful scrubbing action with a deluge of water which removes paint or resin particles from the exhaust air. The design of the nozzles and their spacing provide a curtain of coarse water droplets that trap the particles and carry them into a tank for easy removal. Baffles, which are positioned between the washing area and the exhaust fan, are so positioned as to remove any free water before it reaches the stack. When the air is discharged, it is essentially free of resin and water particles and will contain only organic solvent vapor as a contaminant. Figure 60 shows a typical water wash spray booth.

Water wash sprays are available in a great variety of capacities to efficiently remove air-borne resin particles resulting from spraying operations. In general, standard duty chambers provide sufficient washing capacity for maintenance painting or moderate speed conveyorized jobs, while heavy duty chambers provide extra air washing capability for high production applications involving high coating rates.

Standard air velocities of 125 and 150 feet per minute are offered to meet industry and code standards. Generally, 125 feet per minute meets most requirements. One hundred and fifty feet per minute is available for heavy-duty application or where preferred or specified by industry and codes.

Down-draft Spray Booths

Figure 61 shows a down-draft water wash spray booth. This type of booth is particularly suited for production finishing in many industries; highly adaptable to all kinds of production requirements and plant layouts. The salient features of this device are:

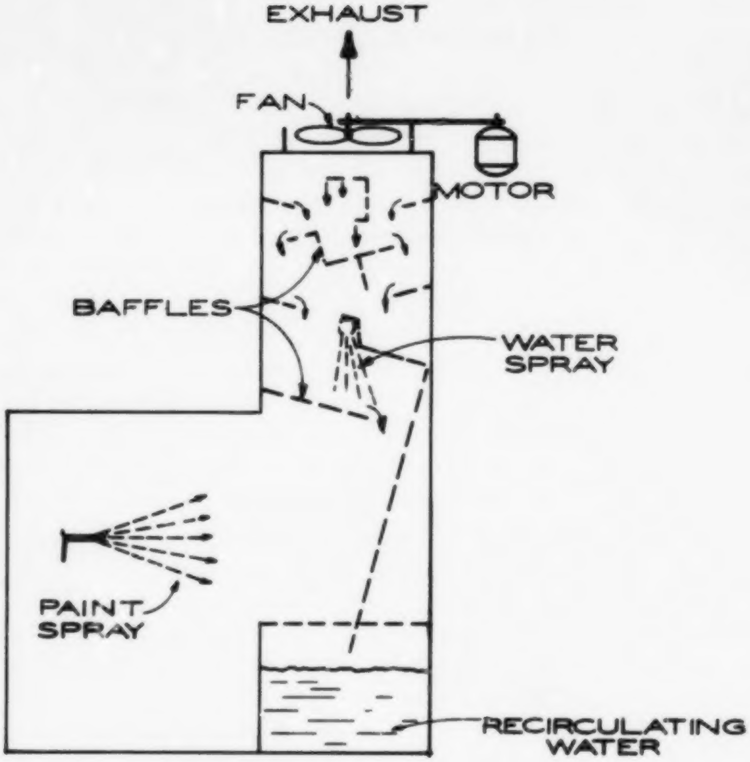

EXHAUST
FAN
MOTOR
BAFFLES
WATER SPRAY
PAINT SPRAY
RECIRCULATING WATER

FIGURE 60

WATER-WASH SPRAY BOOTH

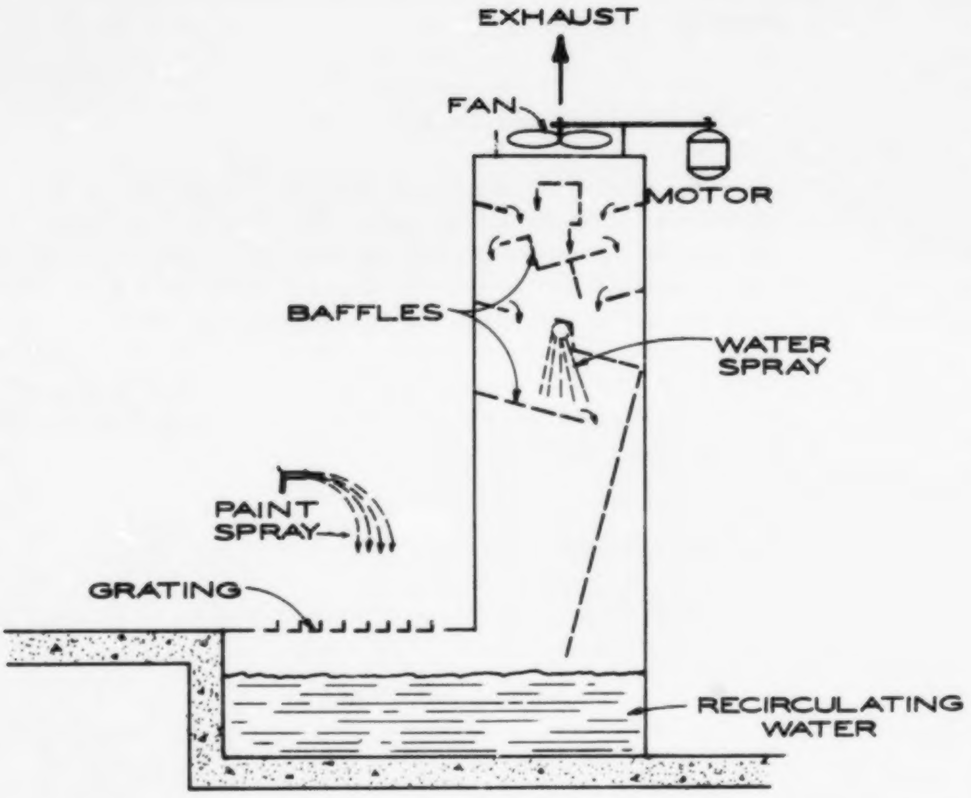

EXHAUST
FAN
MOTOR
BAFFLES
WATER SPRAY
PAINT SPRAY
GRATING
RECIRCULATING WATER

FIGURE 61

DOWN-DRAFT
WATER WASH SPRAY BOOTH

1. The tank of water immediately below the grilled floor where spray particles settle.
2. The water that cascades down the spill sheet of the chamber. This rapidly-flowing water-curtain removes more resin particles from the air.

This type of spray booth is available without enclosure, with semi-enclosure, and with complete enclosure where spray operators can work all around the object being sprayed.

The Electrostatic Coating Booth

The principle of electrostatic spraying is based on the familiar physical law that like charges repel and unlike charges attract. Atomized paint particles are given a negative charge while the product is maintained at ground potential and is positive in relation to the negative paint particles. If some of the charged paint particles bounce off or miss the product, they reverse themselves back to the product because of the attraction due to the electrostatic field. The obvious advantage of electrostatic spraying is a much greater efficiency of paint utilization by minimizing overspray. Spray booth and duct maintenance are correspondingly reduced.

Other Spray Booths

Various other types of spray booths are available for particular operations. Included in this list are:

1. Auto-truck and truck-trailer booths.
2. Automatic spray booths.
3. Degreasing booths.
4. Cleaning booths.
5. Bench and leg booths.
6. Ceramic spray booths.
7. Traveling spray booths.

Detailed descriptions of these booths are best found by referring to manufacturers' literature.

ORGANIC EMISSIONS FROM PROTECTIVE COATING OPERATIONS

The emissions from protective coating operations consist of particulates and volatile organic solvents. The Air Pollution Control District of Los Angeles conducted a survey in 1955, supplemented in 1957, in order to determine the quantities, types and sources of organic compounds in the Los Angeles County atmosphere, exclusive of motor vehicle emissions. Results indicated that protective coating operations accounted for 55 percent of the total organic emissions. This figure accounted for 470,000 pounds of organic vapors being emitted daily into the atmosphere.

The range of average concentration of organic vapors from protective coating operations has been determined from a survey by the Air Pollution Control District of Los Angeles County to be 100 to 200 parts per million. These values are lower than those allowed by safety requirements, based on the lower explosion limit of the individual compounds. Fire prevention regulations usually require that organic emissions not exceed 25% of the lower explosion limit. For toluene, which has wide use in finishes, this would be about 3,000 parts per million. (See Table 96). Although the organic vapors exist at low concentrations, low partial pressures, and low dew points, their presence is still significant as far as air pollution control is concerned. Any abatement method developed for recovery of low concentrations would probably be applicable as well as more attractive economically in those operations where high concentrations are encountered.

The exhaust air rate giving rise to hydrocarbon emissions from surface coating operations is fixed by insurance standards to be not less than 100 feet per minute per square foot of booth opening. The usual spray booth ventilation rate is 100 to 150 feet per minute.

Particulate matter, consisting of fine paint particles, is emitted in surface coating operations. Their presence is quite important, from the point of view of controlling organic solvent emissions, because they interfere with the operation of abatement systems designed to control organic emissions. The concentration of these particles seldom exceeds 0.01 grain per SCF of unfiltered exhaust.

POLLUTION CONTROL CONSIDERATIONS FROM SURFACE COATING OPERATIONS

Particulate Matter

The fraction of paint that is not deposited on an object during the use of the common air atomization spray gun is called overspray. Overspray may be as high as 90 percent; however, 60 percent is more common. Particle emissions from spray booth operations are controlled by baffle plates, filter pads, or water spray curtains. The efficiency of baffle plates and filter pads can be as high as 90%. Water curtains are satisfactory for removing paint particulates with efficiencies up to 95%. A water circulation rate of 10 to 38 gallons per 1,000 cubic feet of exhaust air is customary for this use.

Control of Organic Emissions

Two techniques are available for limiting the emission of organic solvents from surface coating operations. These include:

1. Process modification
2. Pollution control with or without solvent recovery

Under "process modification" there are two conventional alternatives. Emissions can be reduced by a factor of two or three by switching to electrostatic spraying, or the composition of the solvent system may be altered so as to make it exempt from Rule 66.* Table 97 is an example of substitution of exempt solvent.

If none of the alternatives are possible, then add-on pollution abatement equipment is required.

The known methods for pollution control with solvent recovery include the following: condensation by cooling, condensation by compression, absorption and stripping, and adsorption.

Condensation by Cooling

Scheflan and Jacobs[7] indicate that solvent recovery by refrigeration is practical only to mixtures where the hydrocarbon to be recovered is present in greater amounts than 50,000 ppm. Since the concentration of hydrocarbon solvent in spray booth emissions is between 100 and 200 ppm, it is quite clear that this method is not applicable. For detailed calculation see LAAPCD Report #8[6].

Condensation by Compression

In order to demonstrate the applicability of this approach to spray booth emissions, consider toluene to be the organic pollutant of interest. The partial pressure of toluene at 68°F in a surface coating operation is 0.08 mm Hg (100

*Rules and Regulations, County of Los Angeles Air Pollution Control District.

TABLE 97

SUBSTITUTION OF EXEMPT SOLVENT

Typical Solvent Formulation	Vol. %	Limit Under Rule 66
Acetone	25	Exempt
Toluene	50	≤20% in Aggregate
Cellosolve Acetate	25	Exempt
	100	

Exempt Solvent Formulation	Vol. %	Limit Under Rule 66
Acetone	25	Exempt
Benzene	15	Exempt
Toluene	15	≤20%
Paraffinic Hydrocarbon	20	≤20%
Cellosolve Acetate	25	Exempt
	100	

ppm toluene in air at 68°F). Removal of 90% of the toluene at 68°F by compression would require increasing the total pressure on the system to 12,000 psi. This would require a six-stage compressor with a power requirement of (assuming 75% efficiency) 72 hp/1000 ACFM. Both capital and operating costs for such a system would be prohibitive for most cases.

Absorption

According to Ray,[5] when the concentration of an organic vapor to be recovered is low enough to be safe, then recovery by mineral oil absorption is relatively inefficient and expensive. As far as absorption with water is concerned, it is known that lower molecular weight alcohols and ketones have varying degrees of solubility in water. However, the major portion of paint thinners and diluents is either mineral spirits or toluene, and they do not have great solubility in water.

In general, control of solvent emissions by means of absorption is not practical, because the extremely low vapor concentration results in a high capital cost for the scrubbing tower, the stripping tower, and the numerous heat exchangers required.

Adsorption

Activated carbon appears to be the adsorbant most suitable for recovering the organic solvent vapors emitted from spraying operations. Since activated carbon will adsorb all the usual low boiling solvent vapors, it can be used for recovery of any or all low boiling solvents vaporized in surface coating operations.

Various systems have been employed for carbon adsorption. Figure 62 shows a schematic layout for a paint spray application. The adsorption system shown would require a fan or blower to remove the vapor-laden air, two drums containing a bed of activated carbon which would be used alternately (one adsorbing the other being regenerated), a condenser, and some sort of decanter. Controls are also necessary to switch air flows to the adsorbers and control the desorption stream.

There is no question that activated carbon can be used to remove organic vapors from a gas stream by adsorption. The "rule-of-thumb" is that about 1 lb of carbon is needed for 1 ACFM going through the recovery unit. If the concentrations of the organic vapor are very low, this ratio can be reduced to 1/4 lb/ACFM. Another "rule-of-thumb" is that the carbon will adsorb 10 to 20% of its own weight, at which time desorption will be necessary.

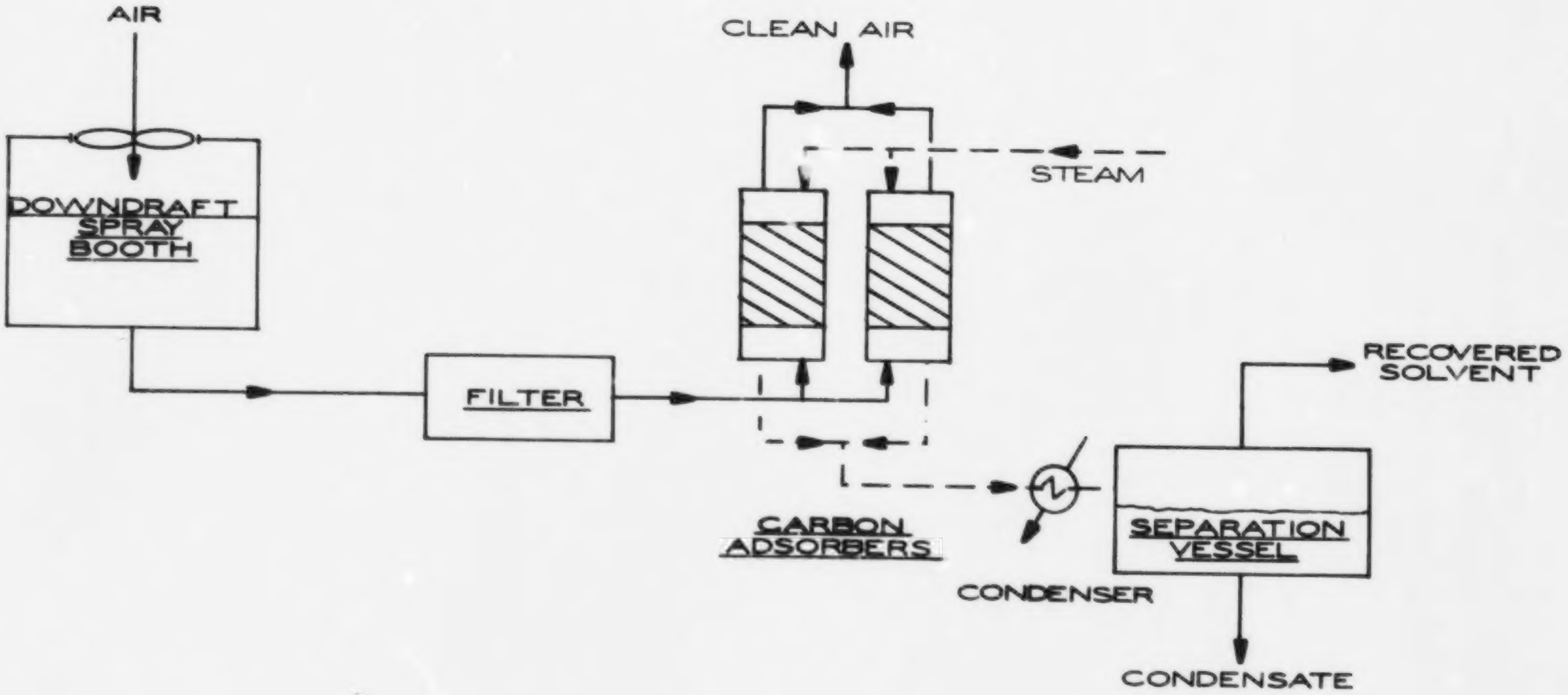

AIR
DOWNDRAFT SPRAY BOOTH
FILTER
CLEAN AIR
STEAM
CARBON ADSORBERS
CONDENSER
SEPARATION VESSEL
RECOVERED SOLVENT
CONDENSATE

FIGURE 62

SCHEMATIC OF CARBON ADSORPTION & DESORPTION UNITS

There are several factors which influence the capacity of a carbon bed for adsorption of an organic solvent:

1. Temperature — the higher the temperature, the lower a bed's capacity.
2. Concentration — the higher the concentration of organic vapor in gas stream, the higher the capacity.
3. Solvent boiling point — higher solvent boiling point increases capacity.
4. Contact time — other things being equal, the longer the contact time, the greater the capacity.
5. Humidity — high humidity will decrease capacity.

The Air Pollution Control District of Los Angeles conducted an extensive pilot plant study of carbon adsorption for the removal of organic solvents from spray booth operations. Table 98 shows the results of sizing several adsorbing units with varying capacities. The main conclusion of their study was that the control of organic emissions from protective coating operations was technically feasible using adsorption on activated carbon.

There has been a significant amount of recent process development in carbon adsorption systems in order to make them more economical. These developments have taken two primary forms:

1. Integration of the carbon adsorption process with the surface coating process. For example, using paint bake oven exhaust gas to desorb the recovered solvent from the carbon bed, or using the heat in a regeneration stream to reduce fuel costs in a surface coating oven.

2. Using the carbon adsorption process to reduce the volume of the solvent laden exhaust gas to be treated by other pollution control systems. For example, thermal incineration can be more economical when applied to the desorption stream from a carbon bed rather than the untreated process exhaust gas stream.

The details of these developments are outside the scope of this paper. They are mentioned here to demonstrate the increasing applicability of carbon adsorption processes to emission control in this industry.

Incineration

Thermal Combustion

Thermal incineration involves direct burning of the effluent in a gas-fired

TABLE 98

SIZES FOR SOLVENT RECOVERY SYSTEMS USING ACTIVATED CARBON*

Spray Booth Capacity	Adsorbing Unit**	Carbon Bed Diameter*** (in.)	Total Carbon Weight (lb)	Solvent Recovered (lb/day)
1,000 cfm	(1)	43	153	13
	(2)	30		
	(3)	30		
	(4)	21 (cone ht, 42")		
5,000 cfm	(1)	96	755	64
	(2)	68		
	(3)	68		
	(4)	48 (cone ht, 42")		
10,000 cfm	(1)	156	1,510	128
	(2)	96		
	(3)	96		
	(4)	60 (cone ht, 150")		
20,000 cfm	(1)	192	3,000	257
	(2)	156		
	(3)	156		
	(4)	96 (cone ht, 192")		
50,000 cfm	(1)	302	7,550	642
	(2)	216		
	(3)	216		
	(4)	144 (cone ht, 312")		

*Operating conditions: solvent toluene at concentration of 150 ppm (= 2.18 lb/hr/1000 cfm); desorption with superheated steam for 2 hr. 45 min., using 13 lb steam/lb solvent recovered; carbon retentivity, 8½ lb solvent/100 lb carbon; work, one 6-hour shift per day, 5 days per week; duct velocity, 2500 fpm; adsorber velocity, 100 fpm.

**Adsorbing units:
(1) single unit, single flat bed; pressure drop, 2.1 in. H_2O
(2) double unit, single flat bed; pressure drop, 2.1 in. H_2O
(3) single unit, two flat beds; pressure drop, 10.0 in. H_2O
(4) single unit, vertical cone bed; pressure drop, 3.1 in. H_2O

***Carbon bed depth, 5.7 in. all units.

incinerator. Although simple in concept and operation, there is actually a great deal of design, engineering, and manufacturing skill involved. The process of thermal incineration is outlined by the flow diagram shown in Figure 63. The solvent laden air from the spray booth enters the thermal system where it is preheated to 600°F to 900°F and then incinerated in the residence chamber at 1000°F to 1500°F. The fumes, when properly incinerated, evolve as carbon dioxide, water, and heated air. Fuel costs can be held to a minimum through the use of heat exchange and recirculation of heated air. Thermal combustion is capable of achieving a high level of effectiveness for removal of organic emissions. Systems can operate continuously at efficiencies of 90% to 100%. Combustion temperatures vary according to the solvent and its concentration. Auto-ignition data, which are available for many organic solvents, can serve as a rough guide to the relative difficulty of combustion; however, having been obtained under optimum combustion conditions, they are not a wholly adequate index.

Catalytic Incineration

An oxidation catalyst may be used to reduce the combustion temperature required for incineration. Combustion of organic emissions in a catalytic incinerator may be self-sustaining, given sufficiently high contaminant concentrations and effluent temperatures. Suter[4] indicates that, where heat contents are of the ordr 10 BTU/ft^3 or more, recycling part of the effluent from the catalyst for preheating becomes practical.

Emissions from surface coating operations exist at very low concentrations (see Table 96) due to limitations imposed by fire insurance and industrial health regulations. Because of this fact, it is reasonable to suppose that a preheat burner would be necessary, and this would deter from the attractiveness of catalytic incineration.

GENERALIZED ECONOMICS FOR SURFACE COATING OPERATIONS

Figures 64 through 69 show the operating cost and total cost (operating cost plus 10% of total installed system cost) for five pollution control systems for surface coating operations. In each case, the concentration of solvent (assumed to be toluene) is 100 ppm. For small systems (500 to 1000 SCFM), catalytic incineration with heat exchange is the most economical method. This is due to the following factors:

1. Credit for solvent recovery is too small to make carbon adsorption attractive.

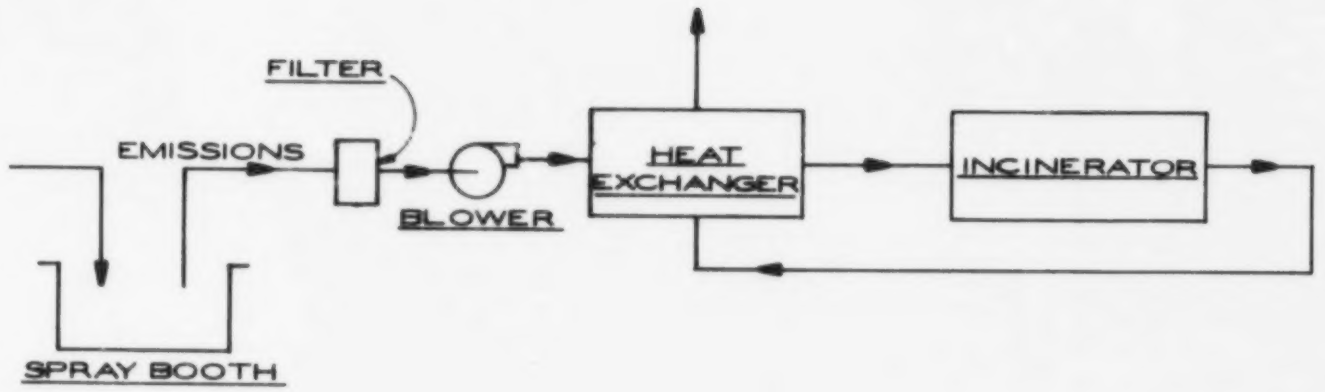

FILTER
EMISSIONS
BLOWER
HEAT EXCHANGER
INCINERATOR
SPRAY BOOTH

FIGURE 63

FLOW DIAGRAM OF THERMAL INCINERATION SYSTEM

2. The fume concentration is low, making natural gas requirements high, which consequently, rules out thermal incineration.

For larger systems (greater than 1000 SCFM), carbon adsorption is the most economical method. This conclusion does not depend upon obtaining any credit for solvent recovery. The economic advantage of carbon adsorption over any incineration method is strictly due to its lower total cost as compared with the other methods.

Figures 70 through 73 show the operating cost and total cost for the same pollution control systems at a solvent concentration of 1000 ppm. If credit for solvent recovery is not considered a factor, then for systems up to 10,000 SCFM, catalytic incineration would be the most economical method. However, if credit for solvent recovery is considered, then carbon adsorption is the method of choice for all systems at this fume concentration.

FIGURE 64

ANNUAL COST FOR CARBON ADSORPTION FOR SURFACE COATING OPERATIONS

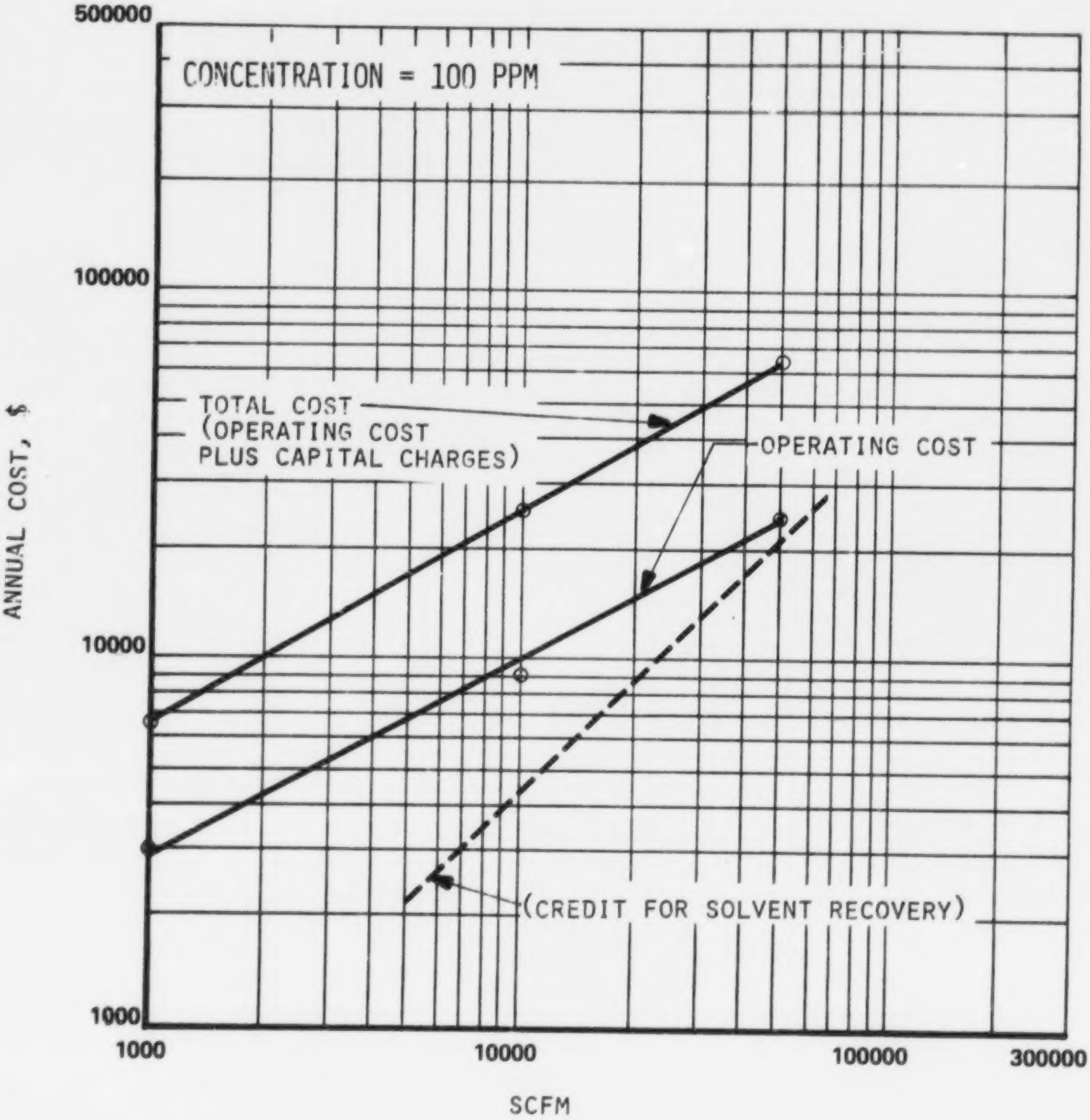


FIGURE 65

ANNUAL COSTS FOR CATALYTIC INCINERATION (WITHOUT HEAT EXCHANGE) FOR SURFACE COATING OPERATIONS

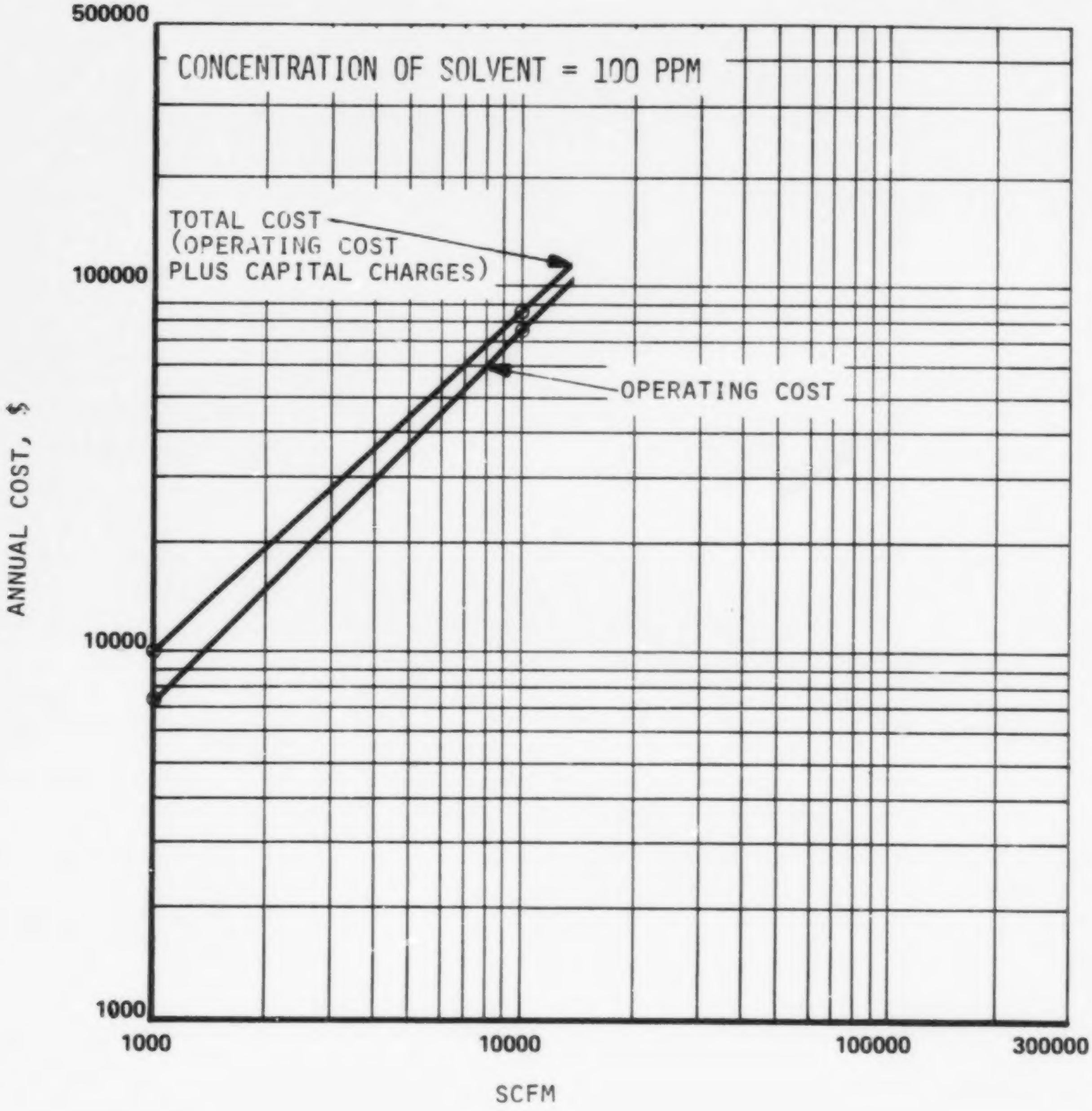


FIGURE 66

ANNUAL COSTS FOR CATALYTIC INCINERATION (WITHOUT HEAT EXCHANGE) FOR SURFACE COATING OPERATIONS

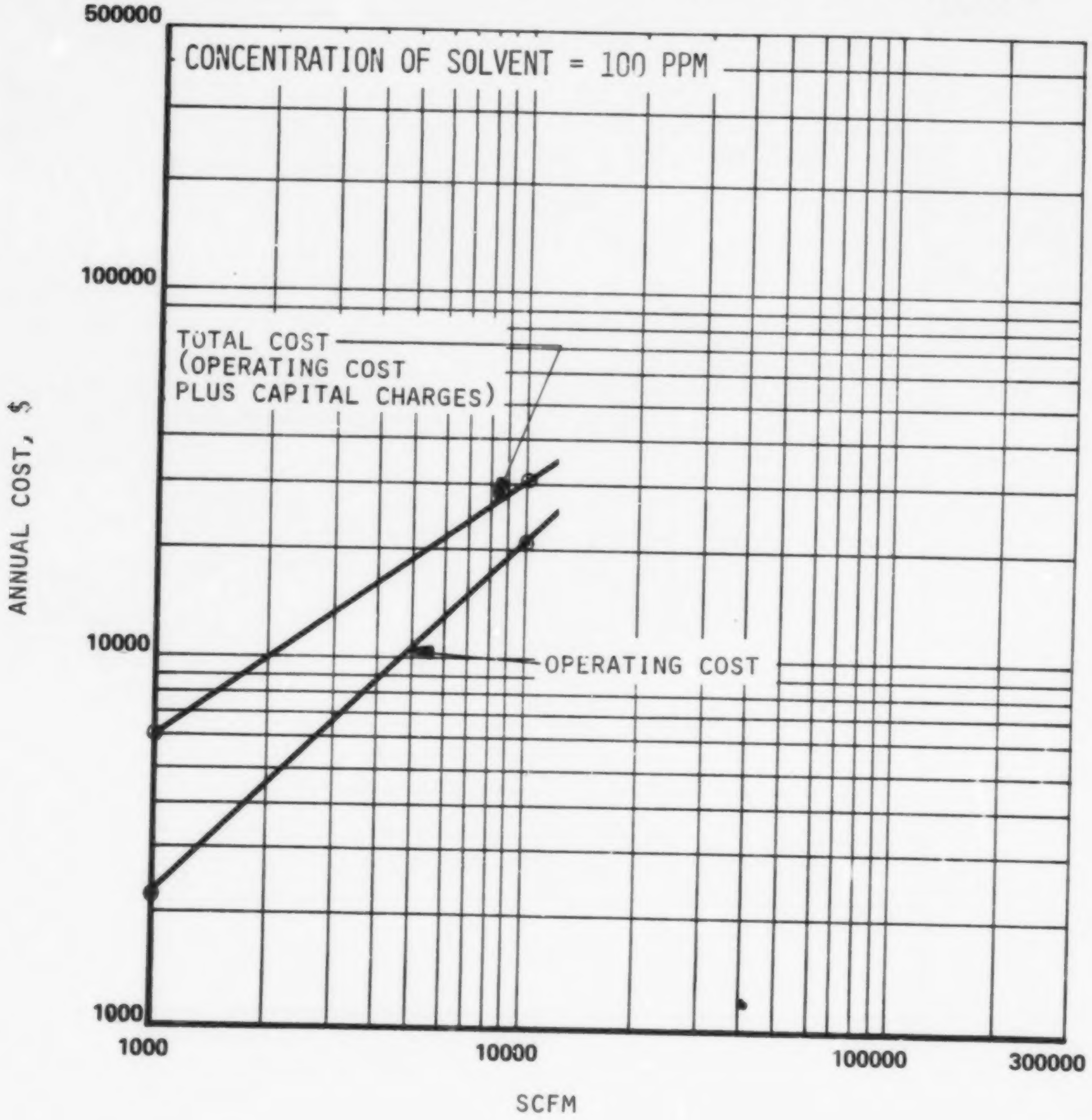


FIGURE 67

ANNUAL COSTS FOR THERMAL INCINERATION
(WITHOUT HEAT EXCHANGE)

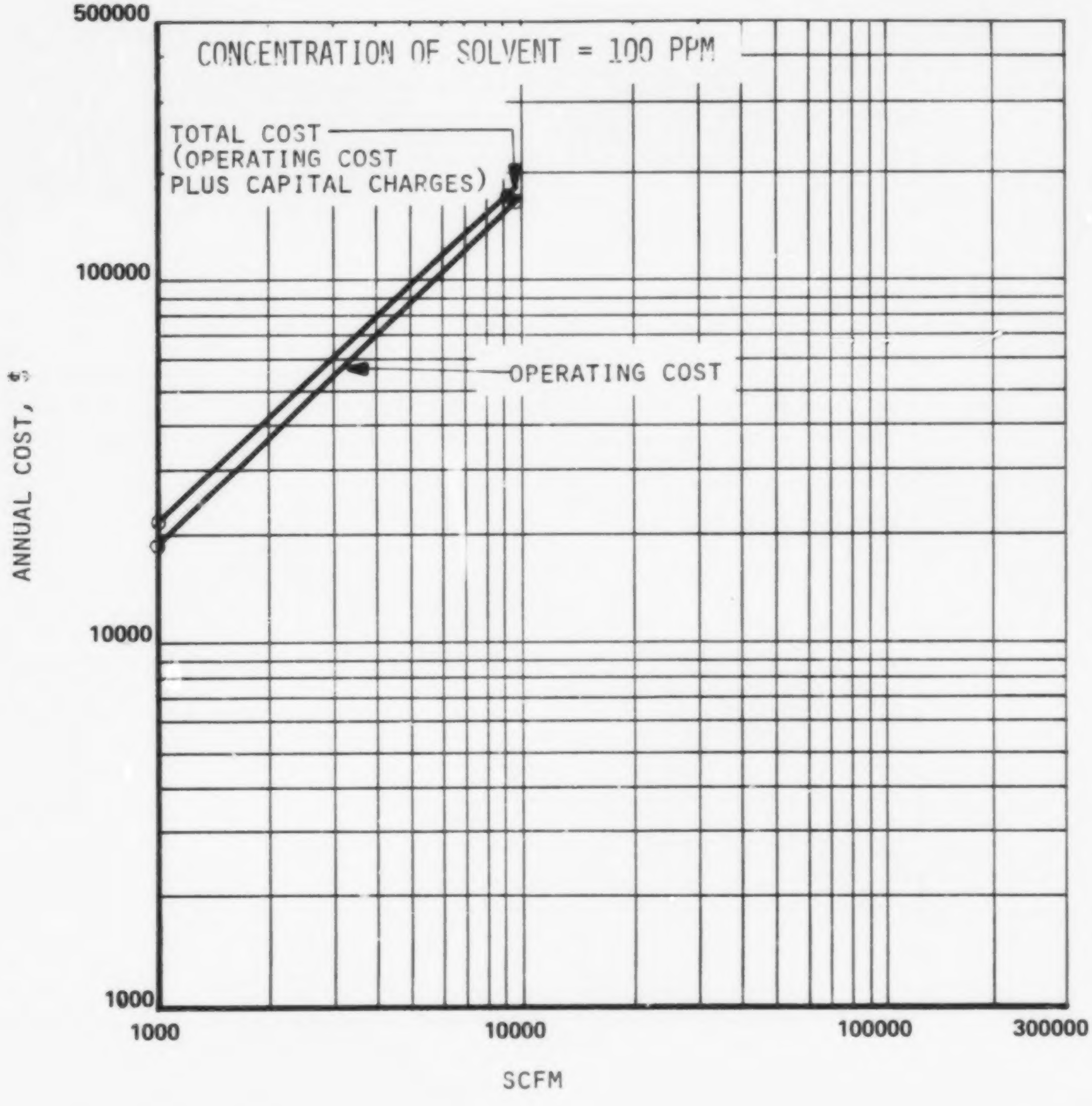


FIGURE 68

ANNUAL COST FOR THERMAL INCINERATION (WITH HEAT EXCHANGE) FOR SURFACE COATING OPERATIONS

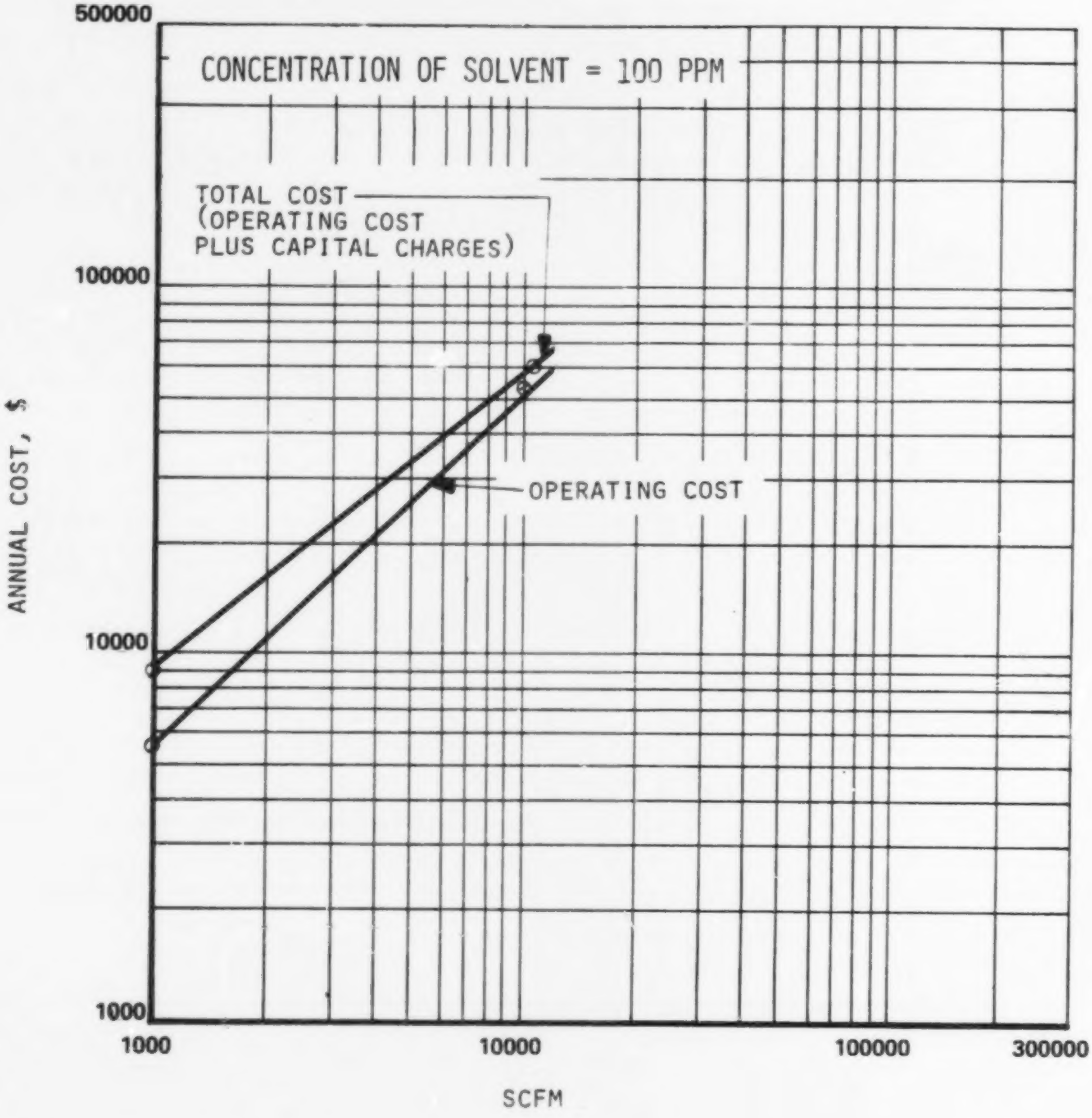


FIGURE 69

ANNUAL COST FOR CARBON ADSORPTION FOR SURFACE COATING OPERATIONS

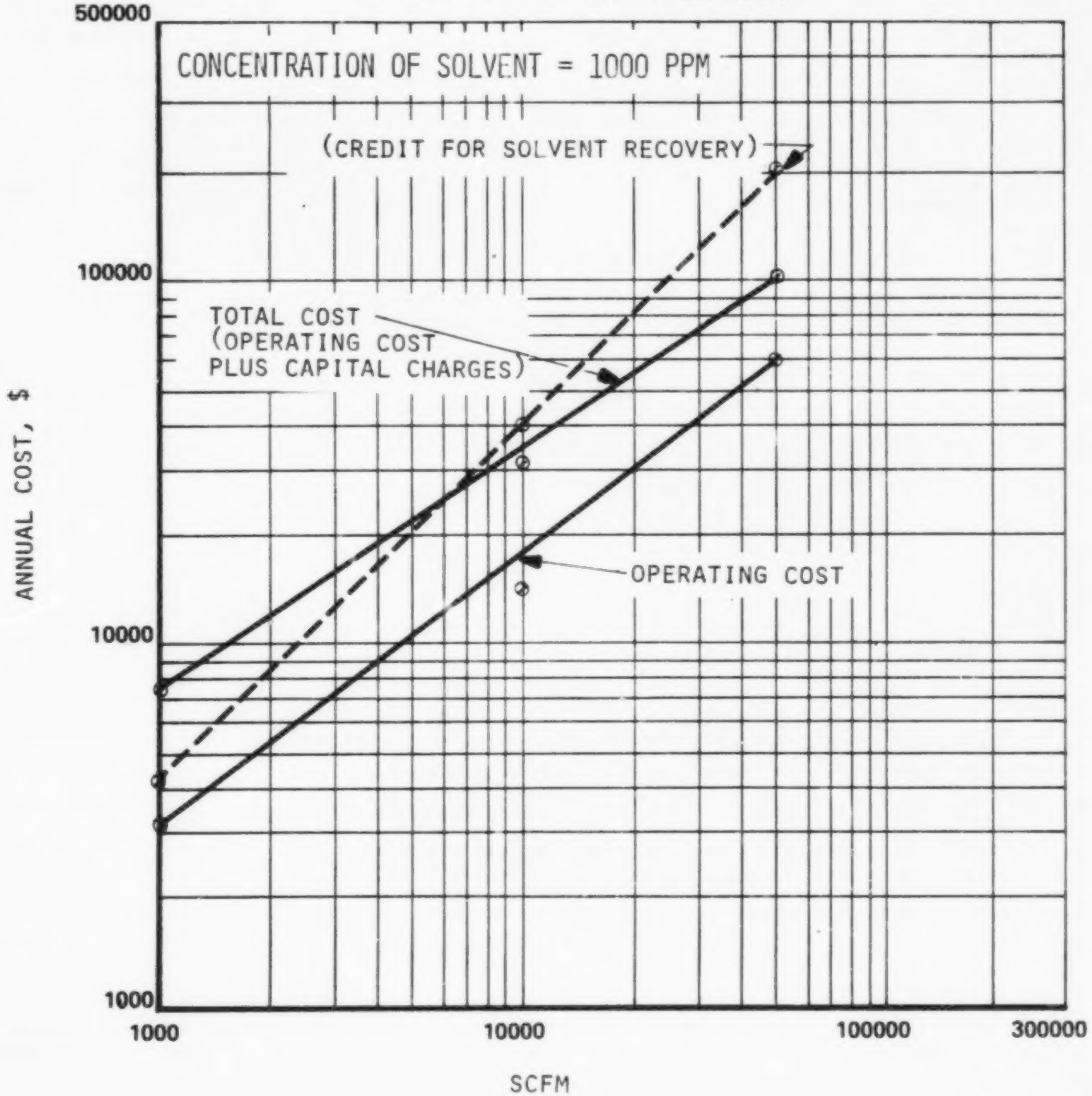


FIGURE 70

ANNUAL COSTS FOR CATALYTIC INCINERATION (WITHOUT HEAT EXCHANGE) FOR SURFACE COATING OPERATIONS

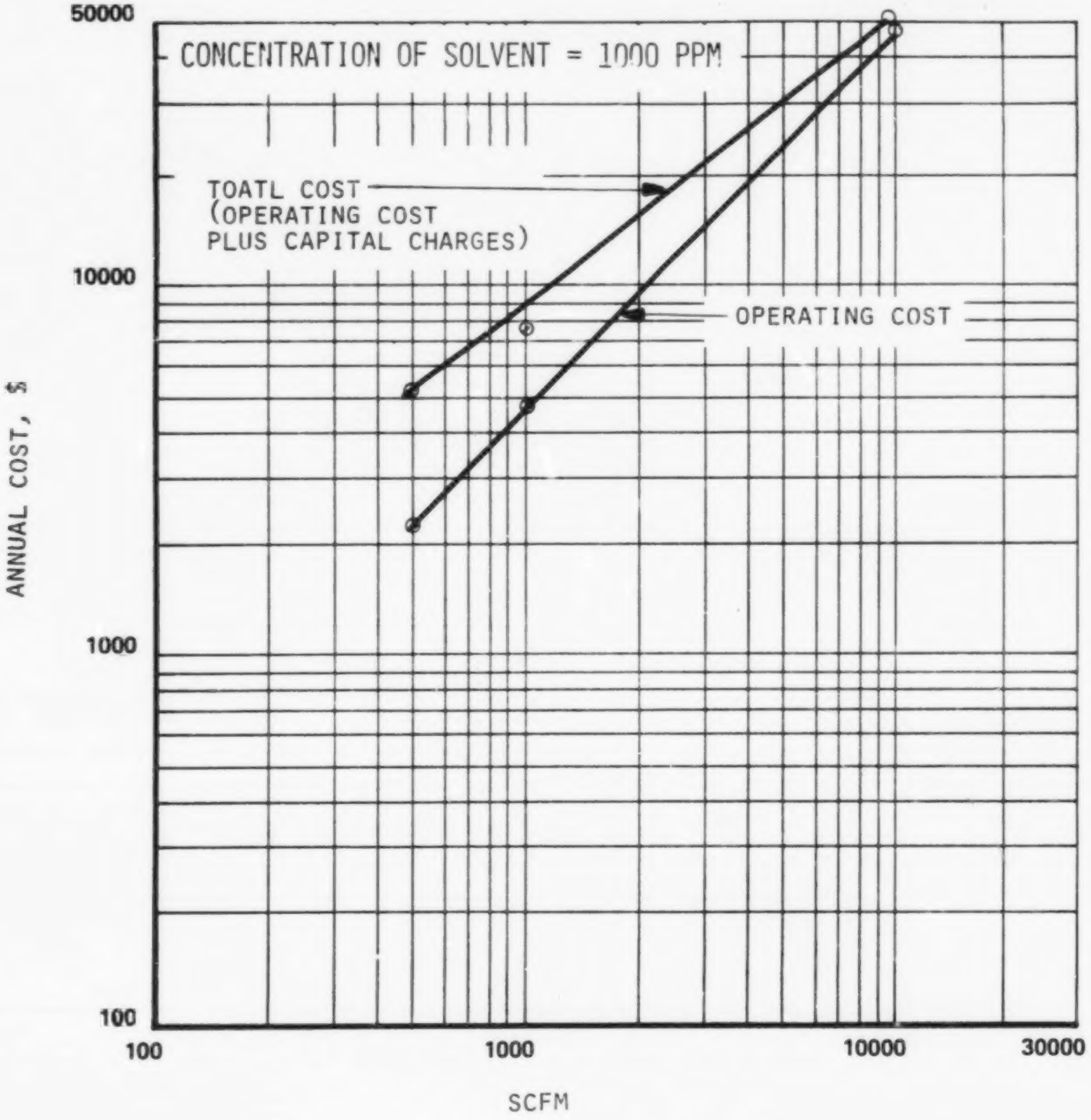


FIGURE 71

ANNUAL COSTS FOR CATALYTIC INCINERATION (WITH HEAT EXCHANGE) FOR SURFACE COATING OPERATIONS

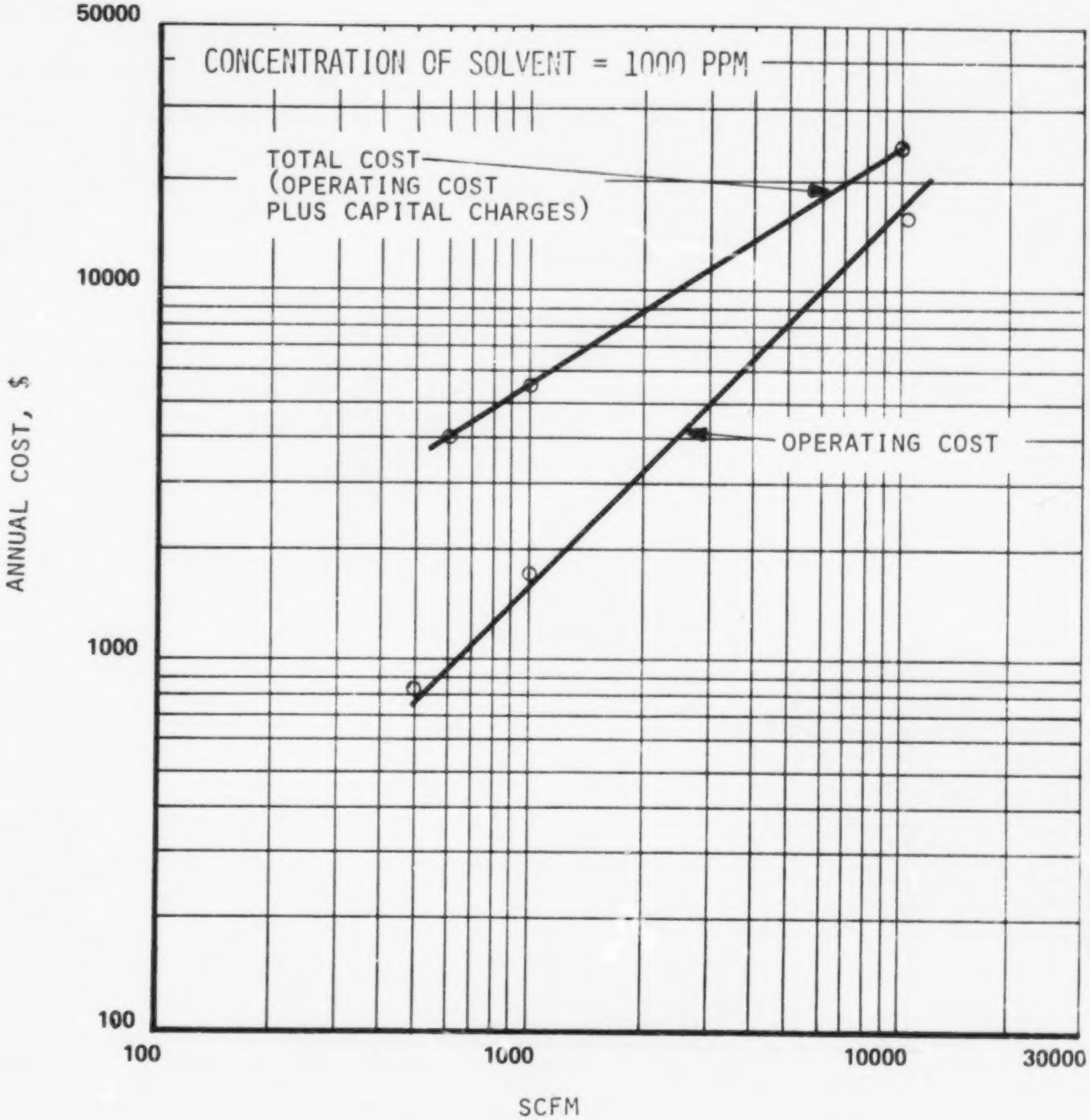


FIGURE 72

ANNUAL COSTS FOR THERMAL INCINERATION
(WITHOUT HEAT EXCHANGE)

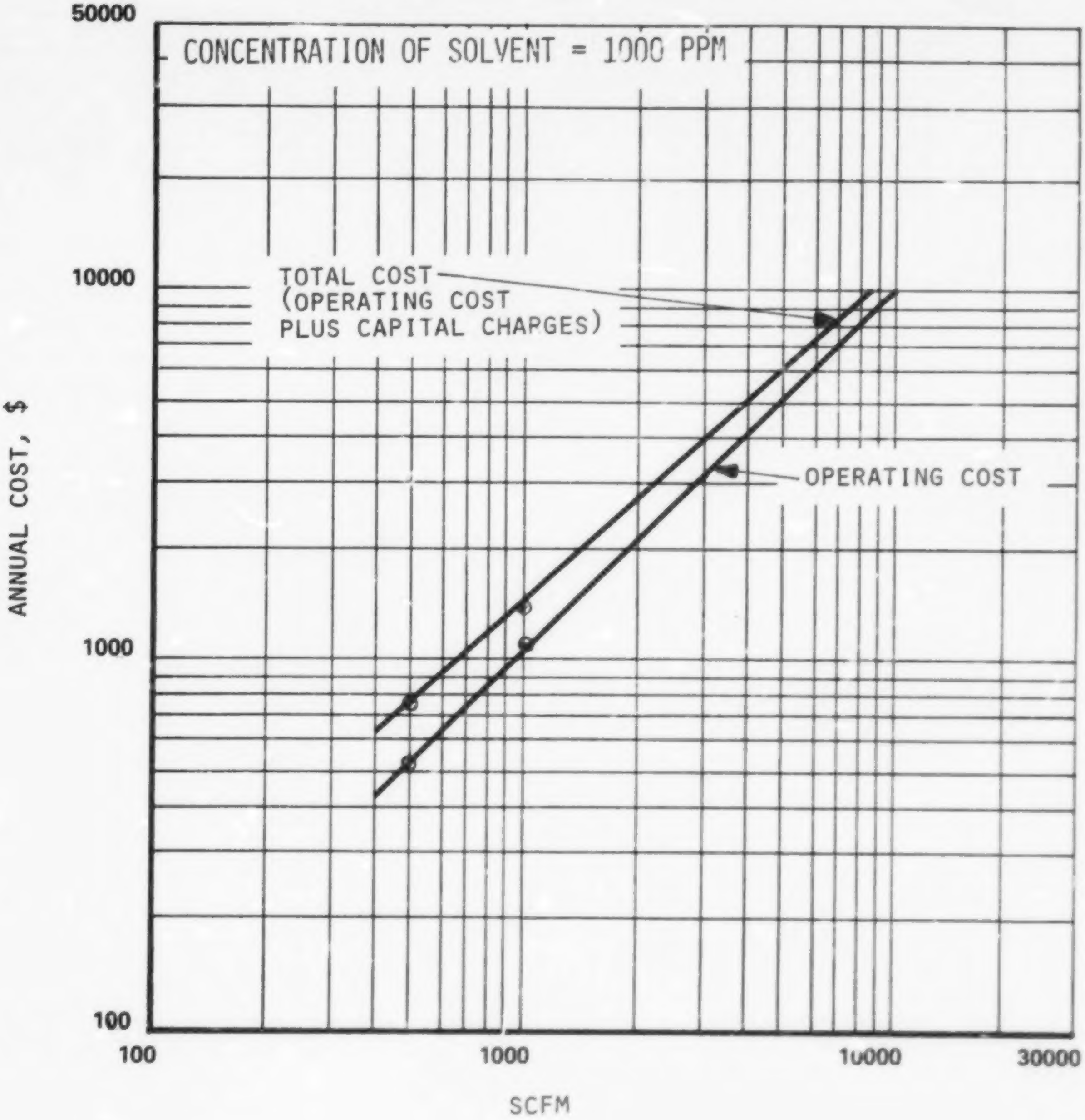
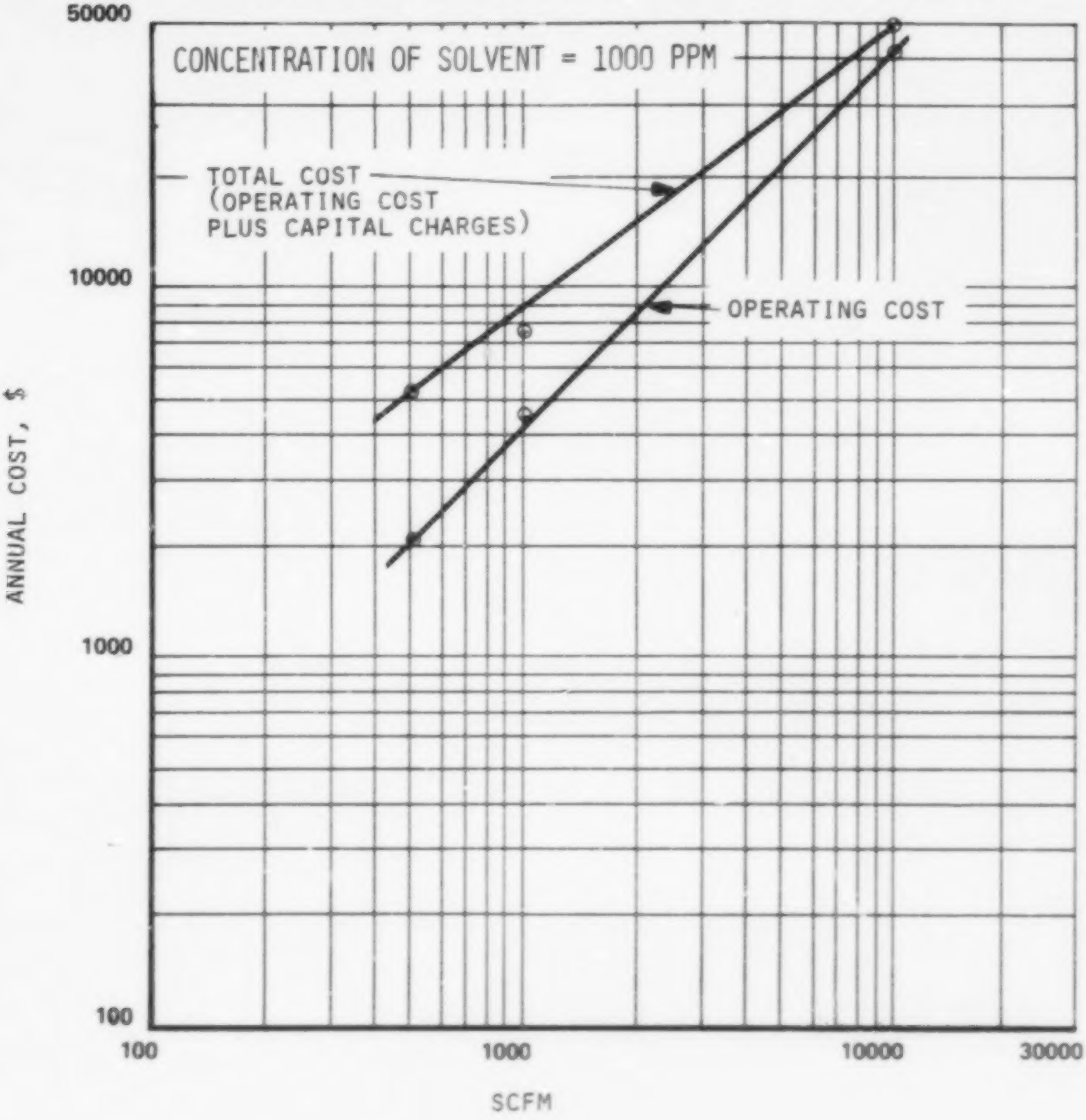


FIGURE 73

ANNUAL COST FOR THERMAL INCINERATION (WITH HEAT EXCHANGE) FOR SURFACE COATING OPERATION



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C. ADDITIONAL COST DATA

The previous section of this report dealt with the cost of air pollution control systems for seven specific processing applications. This section deals with the generalized correlation of costs for each type of control system for all seven of the process applications discussed. The discussion is divided into four parts:

1. A discussion of the annual operating cost basis, including both the direct and capital charge portions of this cost.
2. A discussion of the effects of utility price levels on overall costs.
3. Derivation of capital cost indices for each specific process application.
4. Generalized graphical correlations of capital and operating costs for each type of control system.

1. Discussion of Cost Basis

As noted in the introduction to this report, the total annual cost for a particular control system is the sum of the direct annual operating cost and an annualized capital charge.

In the previous section of this report the annual direct operating costs for air pollution control systems in specific processing applications were calculated using estimates supplied by the equipment manufacturers. These estimates were prepared in terms of the quantity of each operating cost item required, rather than the cost. A standard price was applied to these estimates by the coordinating engineer in order to determine the equivalent cost. The standard prices used are listed below:

Cost Item	Units	Price, $/Unit
Operating Labor		
Operator	man hrs	6
Supervisor	man hrs	8
Maintenance		
Materials	*	*
Labor	man hrs	6
Replacement Parts		
Utilities		
Electric Power	kwh	0.011
Fuel	mm Btu	0.80
Process Water	M Gal	0.25
Cooling Water	M Gal	0.05
Chemicals	*	

The sum of all the above items applied over a year's operation is the direct annual operating cost of the system.

The total annual cost of each system is calculated by adding the annualized capital charges to the direct annual operating cost. In calculating the annualized capital charges, the investment cost of the system, including taxes and interest, must be spread out over the useful life of the equipment. Many methods of annualizing investment cost are used. These methods fall into three major categories:

1. Straight line method which applies the capital charges at a fixed rate over the useful life of tne control system.

2. Accelerated methods which apply the capital charges at a declining rate over the useful life, on the theory that aging or loss in value of equipment occurs to a greater degree on new equipment than on old equipment.

3. Methods which relate capital charges to some measure of equipment usage. These methods are seldom applied to processing equipment. The most common example is mileage-based depreciation of automobiles.

Of the two methods applicable to processing equipment, the most commonly used is the straight line method. This is the method used for the data presented in this report. Reasons for its common use are:

1. It is easy to understand and calculate.

2. It is thought by many to be the best approximation of the rate of obsolescence of process equipment.

3. It makes alternate control systems comparable on an annualized cost basis since the capital charges based upon this method are constant from year to year.

Once the decision has been made to use this method, the only critical issue is what value to use for the useful life of the control system. The useful life of any control system is, in reality, a composite of the useful lives of its component parts. Some of those parts have relatively long lives, others relatively short lives. The value chosen for the economic evaluation of a control system depends upon: the nature of the primary control device, the differences in expected useful life of similar equipment from different manufacturers, the maintenance practices of the owning firm, the battery limits defined for the system, the number and kind of structures built, and the accounting practices of the owning firm, among others. For these reasons, the value chosen will vary from firm to firm even for similar systems.

Taxes may also play a part in the determination of useful life. Under normal circumstances, control systems are depreciated over their normal useful lives. They may, however, be depreciated for tax purposes at an accelerated rate. Under certain circumstances, defined by the Internal Revenue Service, all or part of the air pollution control equipment may be amortized over a sixty month period. In most cases, this period is much shorter than the normal useful life. Accelerated depreciation for tax purposes, especially the sixty month amortization, has the effect of decreasing effective operating cost by deferring tax payments into the future. The discounted value of the cash outflow caused by the operation of the pollution control system is thereby reduced.

The money market at the time of equipment purchase is another important variable in the determination of capital charges. The rate at which money is available varies widely from firm to firm, as well as with overall economic considerations. The cost of capital for financing by means other than borrowing also varies over a wide range from firm to firm. Variations in the cost of financing can be large enough to affect the choice between alternative control systems.

For the purpose of presenting the annual operating cost data in this report, it was decided to use the same fixed percentage of total installed cost as the capital charge for all of the applications studied. The rate chosen was 16%. It was based upon an estimated useful equipment life of 15 to 20 years, debt capital availability at 9 to 11%, and a correction for the tax incentives available to installers of pollution control hardware of 5 to 7%. Although the rate chosen is a good general estimate, it does not purport to be the correct rate for any specific situation. It is used only as a good estimate to assist the cost presentations in this report.

2. Discussion of Utility Price Levels

Evaluation of, and selection among, equivalent control systems should be based upon both the capital cost and the operating cost. Part 1 of this section discussed the capital portion of the total annual operating cost and showed that the direct operating cost is composed of the following items:

Operating (operator and supervisor) Labor

Maintenance Labor and Materials

Replacement Parts

Utilities and Supplies

The utilities portion of the operating cost is a function of utility price levels. Price levels vary due to:

1. Geography — The price of natural gas, for example, is much higher in the New England states than in the Gulf Coast states.

2. Demand — The demand for low sulfur black fuel oil keeps its price as much as 50 cents per barrel higher than the equivalent higher sulfur fuel.

3. Nature of Use — The rates for interruptible gas service are lower than those for continuous service, and rates for peak period use of electrical service are as much as twice the rates for off-hour power consumption.

The effect of utility cost levels also varies within a given type of system. Capital cost is a larger part of the total cost of a small unit than it is of a large unit of the same type. Therefore, the utility costs are smaller relative to the total annual operating cost, and have less effect on it. Also, the operating parameters of a system affect the relative size of the utility costs. Scrubbers using a high pressure drop, for example, require more power to push the gas through, than do scrubbers having a low pressure drop. Therefore, utilities will be a larger portion of the total cost of high energy scrubbers than of low energy scrubbers.

3. Derived Capital Cost Indices

For each of the process applications discussed in the previous sections of this report, capital costs of pollution control equipment have been presented for two or three different process sizes. This permits development of a mathematical expression for the capital cost of air pollution control systems as a function of process size in each application. The mathematical model chosen was the exponential form often used for relating cost and size of capital equipment.

$$\text{Capital Cost} = K\ (\text{Size})^{x}$$

Where

K and x are constants, and

Size is the capacity of the plant to which the abatement equipment is being applied.

This relationship assumes that a log-log plot of cost and size is a straight line for each application. For most types of equipment, this is a good assumption.

The constants K and x were evaluated by computer for each abatement application studied. Calculations were made for each of the three capital cost categories presented in each application:

1. Collector only
2. Collector plus auxiliaries
3. Turnkey system

The units of the "Size" term in the equation for each application are the same as those used in the prior discussion of that application. They are summarized in Table 99.

The results of these calculations for generating capital costs in dollars, are presented in the following tables:

Process Area	Table Numbers
Kraft Pulp Mills	
— Conventional Recovery Furnace	100
— Controlled Odor Recovery Furnace	101
Ferroalloy Furnaces	
— Ferrosilicon Furnace	102
— Silicon Metal Furnace	103
Grain Cleaning Houses	105
Glass-Melting Furnaces	106
Crushed Stone and Aggregate	
— Secondary and Tertiary Rock Crusher	109, 111
— Conveyor Transfer Points	110, 112
Asphalt Saturation	
— Asphalt Saturator	113, 114, 115
— Asphalt Blow Still	116

Also shown in these tables are the ratios of turnkey system cost to collector cost, total equipment cost to collector cost, and turnkey system cost to total equipment cost.

Calculated values of the exponents for the power function can be summarized by equipment type as follows:

Equipment Type	Maximum Value	Minimum Value	Arithmetic Average
Fabric Filters			
Collector Only	.967	.569	.804
Turnkey System	.933	.522	.761
Glass Fiber Mat Filters			
Collector Only	—	—	.647
Turnkey System	—	—	.728
Wet Scrubbers			
Collector Only	.851	.430	.589
Turnkey System	.417	.276	.356
Electrostatic Precipitators			
Collector Only	.859	.436	.730
Turnkey System	.780	.327	.656
Incinerators			
Collector Only	.947	.672	.810
Turnkey System	.771	.562	.667

Of the five types of systems involved, fabric filters had the highest average exponent. This was to be expected since fabric filtering equipment tends to be additive. That is, to increase the capacity of a fabric filter system, one can many times add another unit. This becomes more practicable with larger air flows. Many of the fabric filter systems were under 100,000 ACFM. Had more been in the 200,000-and-up range, the cost-to-size relationship would have been even closer to linear.

The exponent for incinerators had an average value of .667 over the 10 - 50,000 ACFM size range. This was above the 0.4 exponent usually assumed, because a number of the incinerators were of relatively larger size.

Every incinerator, regardless of size, requires an extensive system of safety control devices to prevent explosions. This system is a significant part of the cost of smaller incinerators. So in that size range, the cost of increasing size is relatively small.

TABLE 99

UNITS OF PLANT SIZE FOR EACH PROCESS AREA

Process Area	Plant Size Units	
Kraft Pulp Mills	ADT/day	Plant Capacity
Ferroalloy Furnaces	Lb/hour	Product
Grain Cleaning Houses	Lb/hour	Process Weight
Glass-Melting Furnaces	Ton/day	Glass Output
Crushed Stone and Aggregate		
— Secondary and Tertiary Rock Crusher	Ton/hour	Process Weight
— Conveyor Transfer Points	ACFM	Inlet Gas Flow
Asphalt Saturation	ACFM	Process Gas Flow

The average exponent derived for glass mat fiber filters was .647. The limited amount of data on these systems precludes drawing many conclusions, but the cost data correlations for them could be expected to resemble those for fabric filters.

Wet scrubbers had an average exponent of .589 — approximately equal to the 0.6 usually assumed for equipment. Every one of the scrubbers had an inlet gas flow rate below 100,000 ACFM. In this range the basic design of scrubbers is adequate to handle these volumes of gas and the cost starts increasing gradually with size.

Exponents for electrostatic precipitators varied from .436 to .859, with an average value of .73. In most applications the gas flow was above 100,000 ACFM. Precipitator flow rates from 300,000 to 600,000 ACFM are not unusual. A major capital expense of precipitators is the power supply that is required. This costs nearly as much for small precipitators as for large ones. Therefore, the cost of small precipitators does not increase as rapidly with size as would be expected in larger designs.

The use of the derived capital cost equations outside the range of the data from which they were calculated is valid within certain limitations. Very small equipment installations tend to have relatively high capital costs which do not correlate well with size. Small systems cost roughly the same regardless of the treated gas throughput. Very large systems are frequently based on different designs than their smaller counterparts, or are composed of several smaller units. Consequently, the derived cost indices will be inaccurate for these larger sizes. Numerical values for these large and small limitations depend upon both the nature of the abatement equipment and the nature of the process to which it is applied. Generalizations of these numerical values can be made, however, and they are presented below as guidelines.

	Small Limit, ACFM	Large Limit, ACFM
Scrubbers	2,000	100,000
Fabric Filters	2,000	very large
Precipitators	50,000	very large
Incinerators	20,000	50,000

The basic capital cost data collected were also used to calculate the cost per SCFM of inlet gas for each application. Results of these calculations are presented in the following tables:

Process Area	Table Numbers
Kraft Pulp Mills	
— Conventional Recovery Furnace	117
— Controlled Odor Recovery Furnace	118
Ferroalloy Furnaces	
— Ferrosilicon Furnace	119
— Silicon Metal Furnace	120
Grain Cleaning Houses	121
Glass-Melting Furnaces	122, 123, 124
Crushed Stone and Aggregate	
— Secondary and Tertiary Rock Crusher	125, 127
— Conveyor Transfer Points	126, 128
Asphalt Saturation	
— Asphalt Saturator	129, 130, 131
— Asphalt Blow Still	132

TABLE 100

DERIVED COST INDICES FOR KRAFT MILL RECOVERY FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
ELECTROSTATIC PRECIPITATOR LA PROCESS WEIGHT					
COLLECTOR ONLY (A)	3,848	.773	-	-	-
TOTAL EQUIPMENT (B)	4,699	.759	-	-	-
TURNKEY (C)	18,134	.675	-	-	-
SMALL	-	-	1.119	2.562	2.289
LARGE	-	-	1.102	2.302	2.088
ELECTROSTATIC PRECIPITATOR HIGH EFFICIENCY					
COLLECTOR ONLY (A)	2,570	.859	-	-	-
TOTAL EQUIPMENT (B)	3,583	.826	-	-	-
TURNKEY (C)	12,723	.749	-	-	-
SMALL	-	-	1.137	2.502	2.200
LARGE	-	-	1.097	2.219	2.022

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 101

DERIVED COST INDICES FOR KRAFT MILL CONTROLLED ODOR FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
ELECTROSTATIC PRECIPITATOR LA PROCESS WEIGHT					
COLLECTOR ONLY (A)	4,854	.772	-	-	-
TOTAL EQUIPMENT (B)	5,776	.768	-	-	-
TURNKEY (C)	14,622	.750	-	-	-
SMALL	-	-	1.160	2.626	2.264
LARGE	-	-	1.156	2.565	2.219
ELECTROSTATIC PRECIPITATOR HIGH EFFICIENCY					
COLLECTOR ONLY (A)	4,617	.809	-	-	-
TOTAL EQUIPMENT (B)	5,471	.803	-	-	-
TURNKEY (C)	13,739	.780	-	-	-
SMALL	-	-	1.140	2.479	2.174
LARGE	-	-	1.133	2.401	2.119

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 102

DERIVED COST INDICES FOR FERROSILICON FURNACE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTER LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTER HIGH EFFICIENCY					
COLLECTOR ONLY (A)	382	.937	-	-	-
TOTAL EQUIPMENT (B)	554	.927	-	-	-
TURNKEY (C)	947	.928	-	-	-
SMALL	-	-	1.325	2.300	1.735
LARGE	-	-	1.319	2.291	1.736

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 103

DERIVED COST INDICES FOR SILICON METAL FURNACE (DILUTION COOLING)

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTERS HIGH EFFICIENCY					
COLLECTOR ONLY (A)	459	.967	-	-	-
TOTAL EQUIPMENT (B)	728	.946	-	-	-
TURNKEY (C)	1,403	.933	-	-	-
SMALL	-	-	1.345	2.350	1.747
LARGE	-	-	1.330	2.309	1.736

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 104

DERIVED COST INDICES FOR SILICON METAL FURNACE (EVAPORATIVE COOLING)

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	255	.933	-	-	-
TOTAL EQUIPMENT (B)	616	.881	-	-	-
TURNKEY (C)	1,252	.861	-	-	-
SMALL	-	-	1.622	2.828	1.743
LARGE	-	-	1.580	2.726	1.725

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 105

DERIVED COST INDICES FOR GRAIN CLEANING HOUSE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTERS HIGH EFFICIENCY					
COLLECTOR ONLY (A)	14	.722	-	-	-
TOTAL EQUIPMENT (B)	18	.739	-	-	-
TURNKEY (C)	79	.678	-	-	-
SMALL	-	-	1.514	3.846	2.540
LARGE	-	-	1.547	3.650	2.360

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 106

DERIVED COST INDICES FOR GLASS-MELTING FURNACE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
ELECTROSTATIC PRECIPITATOR					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
ELECTROSTATIC PRECIPITATOR					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	12,656	.436	-	-	-
TOTAL EQUIPMENT (B)	15,192	.428	-	-	-
TURNKEY (C)	79,681	.327	-	-	-
SMALL	-	-	1.156	3.805	3.291
LARGE	-	-	1.146	3.374	2.945

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 107

DERIVED COST INDICES FOR GLASS-MELTING FURNACE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBER					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	1,933	.430	-	-	-
TOTAL EQUIPMENT (B)	8,307	.489	-	-	-
TURNKEY (C)	24,693	.385	-	-	-
SMALL	-	-	5.648	10.385	1.839
LARGE	-	-	6.028	9.885	1.640

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 108

DERIVED COST INDICES FOR GLASS-MELTING FURNACE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTER					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTER					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	5,745	.569	-	-	-
TOTAL EQUIPMENT (B)	8,636	.573	-	-	-
TURNKEY (C)	23,839	.522	-	-	-
SMALL	-	-	1.532	3.350	2.186
LARGE	-	-	1.539	3.183	2.068

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 109

DERIVED COST INDICES FOR SECONDARY AND TERTIARY ROCK CRUSHER

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBER LA PROCESS WEIGHT					
COLLECTOR ONLY (A)	426	.618	-	-	-
TOTAL EQUIPMENT (B)	1,301	.592	-	-	-
TURNKEY (C)	11,292	.417	-	-	-
SMALL	-	-	2.630	8.389	3.190
LARGE	-	-	2.536	6.343	2.501
WET SCRUBBER HIGH EFFICIENCY					
COLLECTOR ONLY (A)	360	.644	-	-	-
TOTAL EQUIPMENT (B)	4,085	.450	-	-	-
TURNKEY (C)	16,563	.377	-	-	-
SMALL	-	-	3.752	10.049	2.678
LARGE	-	-	2.867	6.942	2.422

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 110

DERIVED COST INDICES FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS LA PROCESS WEIGHT					
COLLECTOR ONLY (A)	118	.485	-	-	-
TOTAL EQUIPMENT (B)	379	.474	-	-	-
TURNKEY (C)	7,596	.276	-	-	-
SMALL	-	-	2.919	10.930	3.744
LARGE	-	-	2.884	8.694	3.015
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY (A)	96	.506	-	-	-
TOTAL EQUIPMENT (B)	381	.483	-	-	-
TURNKEY (C)	7,803	.279	-	-	-
SMALL	-	-	3.251	11.677	3.592
LARGE	-	-	3.170	9.096	2.869

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 111

DERIVED COST INDICES FOR SECONDARY AND TERTIARY ROCK CRUSHER

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	374	.797	-	-	-
TOTAL EQUIPMENT (B)	647	.772	-	-	-
TURNKEY (C)	1,209	.762	-	-	-
SMALL	-	-	1.508	2.658	1.762
LARGE	-	-	1.459	2.534	1.738

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 112

DERIVED COST INDICES FOR CRUSHED STONE AND AGGREGATE TRANSFER POINTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTER					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
FABRIC FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	26	.704	-	-	-
TOTAL EQUIPMENT (B)	36	.715	-	-	-
TURNKEY (C)	126	.644	-	-	-
SMALL	-	-	1.529	2.956	1.933
LARGE	-	-	1.549	2.769	1.788

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 113

DERIVED COST INDICES FOR ASPHALT SATURATOR

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY (A)	2.5	.851	-	-	-
TOTAL EQUIPMENT (B)	48	.657	-	-	-
TURNKEY (C)	1,600	.400	-	-	-
SMALL	-	-	2.710	6.933	2.558
LARGE	-	-	2.299	4.731	2.057

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 114

DERIVED COST INDICES FOR ASPHALT SATURATOR (WITH H.E.)

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
THERMAL INCINERATORS					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)	9	.947	-	-	-
TOTAL EQUIPMENT (B)	10	.941	-	-	-
TURNKEY (C)	99	.771	-	-	-
SMALL	-	-	1.079	1.863	1.726
LARGE	-	-	1.074	1.604	1.494
THERMAL INCINERATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	9	.947	-	-	-
TOTAL EQUIPMENT (B)	10	.941	-	-	-
TURNKEY (C)	99	.771	-	-	-
SMALL	-	-	1.079	1.863	1.726
LARGE	-	-	1.074	1.604	1.494

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 115

DERIVED COST INDICES FOR ASPHALT SATURATOR

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
GLASS FIBER MAT FILTERS					
LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
GLASS FIBER MAT FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY (A)	96	.647	-	-	-
TOTAL EQUIPMENT (B)	75	.694	-	-	-
TURNKEY (C)	3,35[illegible]	.428	-	-	-
SMALL	-	-	1.248	3.925	3.146
LARGE	-	-	1.298	3.259	2.510

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 116

DERIVED COST INDICES FOR ASPHALT BLOW STILL

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
THERMAL INCINERATOR LA PROCESS WEIGHT					
COLLECTOR ONLY (A)					
TOTAL EQUIPMENT (B)					
TURNKEY (C)					
SMALL					
LARGE					
THERMAL INCINERATOR HIGH EFFICIENCY					
COLLECTOR ONLY (A)	132	.672	-	-	-
TOTAL EQUIPMENT (B)	121	.689	-	-	-
TURNKEY (C)	751	.562	-	-	-
SMALL	-	-	1.068	2.044	1.913
LARGE	-	-	1.090	1.796	1.648

FOR USE IN EQUATION: COST = K(SIZE)**X

TABLE 117

DERIVED COST PER SCFM* FOR KRAFT MILL RECOVERY FURNACES

COLLECTOR TYPE	SMALL	LARGE
ELECTROSTATIC PRECIPITATOR		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	173,600	520,800
COLLECTOR ONLY	2.70	2.11
TOTAL EQUIPMENT	3.03	2.32
TURNKEY SYSTEM	6.93	4.85
ELECTROSTATIC PRECIPITATOR		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	173,600	520,800
COLLECTOR ONLY	3.08	2.63
TOTAL EQUIPMENT	3.50	2.89
TURNKEY SYSTEM	7.70	5.85

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*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

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TABLE 118

DERIVED COST PER SCFM* FOR KRAFT MILL CONTROLLED ODOR FURNACES

COLLECTOR TYPE	SMALL	LARGE
ELECTROSTATIC PRECIPITATOR MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	155,800	467,400
COLLECTOR ONLY	3.78	2.94
TOTAL EQUIPMENT	4.38	3.40
TURNKEY SYSTEM	9.92	7.54
ELECTROSTATIC PRECIPITATOR HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	155,800	467,400
COLLECTOR ONLY	4.52	3.67
TOTAL EQUIPMENT	5.16	4.15
TURNKEY SYSTEM	11.21	8.80

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 119

DERIVED COST PER SCFM* FOR FERROSILICON FURNACES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
FABRIC FILTER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	462,500	740,000
COLLECTOR ONLY	2.72	2.65
TOTAL EQUIPMENT	3.61	3.49
TURNKEY SYSTEM	6.26	6.06

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 120

DERIVED COST PER SCFM* FOR SILICON METAL FURNACES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTERS		
HIGH EFFICIENCY (DILUTION COOLING)		
GAS FLOW RATE, SCFM*	277,500	462,500
COLLECTOR ONLY	2.76	2.72
TOTAL EQUIPMENT	3.71	3.62
TURNKEY SYSTEM	6.48	6.28
FABRIC FILTERS		
HIGH EFFICIENCY (EVAP. COOLING)		
GAS FLOW RATE, SCFM*	109,000	181,700
COLLECTOR ONLY	3.00	2.91
TOTAL EQUIPMENT	4.86	4.59
TURNKEY SYSTEM	8.48	7.92

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*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 121

DERIVED COST PER SCFM* FOR GRAIN CLEANING HOUSES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTER MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
FABRIC FILTER HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	14,900	44,600
COLLECTOR ONLY	0.83	0.66
TOTAL EQUIPMENT	1.26	1.02
TURNKEY SYSTEM	3.19	2.41

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 122

DERIVED COST PER SCFM* FOR GLASS-MELTING FURNACES

COLLECTOR TYPE	SMALL	LARGE
ELECTROSTATIC PRECIPITATOR MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
ELECTROSTATIC PRECIPITATOR HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	11,200	26,800
COLLECTOR ONLY	8.42	5.68
TOTAL EQUIPMENT	9.73	6.51
TURNKEY SYSTEM	32.04	19.17

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 123

DERIVED COST PER SCFM* FOR GLASS-MELTING FURNACES

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
WET SCRUBBER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	11,200	26,800
COLLECTOR ONLY	1.25	0.84
TOTAL EQUIPMENT	7.05	5.04
TURNKEY SYSTEM	12.97	8.27

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 124

DERIVED COST PER SCFM* FOR GLASS-MELTING FURNACES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTER MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
FABRIC FILTER HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	11,200	26,800
COLLECTOR ONLY	7.04	5.50
TOTAL EQUIPMENT	10.79	8.46
TURNKEY SYSTEM	23.59	17.50

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 125

DERIVED COST PER SCFM* FOR SECONDARY AND TERTIARY ROCK CRUSHER

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	19,600	68,700
COLLECTOR ONLY	0.74	0.50
TOTAL EQUIPMENT	1.94	1.26
TURNKEY SYSTEM	6.20	3.15
WET SCRUBBER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	19,600	68,700
COLLECTOR ONLY	0.72	0.50
TOTAL EQUIPMENT	2.71	1.44
TURNKEY SYSTEM	7.26	3.49

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*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 126

DERIVED COST PER SCFM* FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	4,900	14,700
COLLECTOR ONLY	1.49	0.85
TOTAL EQUIPMENT	4.36	2.45
TURNKEY SYSTEM	16.33	7.38
WET SCRUBBER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	4,900	14,700
COLLECTOR ONLY	1.46	0.85
TOTAL EQUIPMENT	4.76	2.70
TURNKEY SYSTEM	17.10	7.74

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 127

DERIVED COST PER SCFM* FOR SECONDARY AND TERTIARY ROCK CRUSHER

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
FABRIC FILTER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	19,600	68,700
COLLECTOR ONLY	1.79	1.54
TOTAL EQUIPMENT	2.71	2.25
TURNKEY SYSTEM	4.77	3.91

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 128

DERIVED COST PER SCFM* FOR CRUSHED STONE AND AGGREGATE CONVEYOR TRANSFER POINTS

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
FABRIC FILTER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	4,900	14,700
COLLECTOR ONLY	2.10	1.52
TOTAL EQUIPMENT	3.21	2.35
TURNKEY SYSTEM	6.21	4.20

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 129

DERIVED COST PER SCFM* FOR ASPHALT SATURATOR

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
WET SCRUBBER		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	20,000	50,000
COLLECTOR ONLY	0.64	0.53
TOTAL EQUIPMENT	1.73	1.21
TURNKEY SYSTEM	4.43	2.49

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 130

DERIVED COST PER SCFM* FOR ASPHALT SATURATOR

COLLECTOR TYPE	SMALL	LARGE
THERMAL INCINERATOR (W/HEAT EX.)		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	20,000	50,000
COLLECTOR ONLY	6.04	5.40
TOTAL EQUIPMENT	6.52	5.79
TURNKEY SYSTEM	11.25	8.65
THERMAL INCINERATOR (W/HEAT EX.)		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	20,000	50,000
COLLECTOR ONLY	6.04	5.40
TOTAL EQUIPMENT	6.52	5.79
TURNKEY SYSTEM	11.25	8.65

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 131

DERIVED COST PER SCFM* FOR ASPHALT SATURATOR

COLLECTOR TYPE	SMALL	LARGE
GLASS FIBER MAT FILTER MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
GLASS FIBER MAT FILTER HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	20,000	50,000
COLLECTOR ONLY	3.14	2.17
TOTAL EQUIPMENT	3.92	2.82
TURNKEY SYSTEM	12.32	7.08

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

TABLE 132

DERIVED COST PER SCFM* FOR ASPHALT BLOW STILL

COLLECTOR TYPE	SMALL	LARGE
THERMAL INCINERATOR		
MEDIUM EFFICIENCY		
GAS FLOW RATE, SCFM*	-	-
COLLECTOR ONLY	-	-
TOTAL EQUIPMENT	-	-
TURNKEY SYSTEM	-	-
THERMAL INCINERATOR		
HIGH EFFICIENCY		
GAS FLOW RATE, SCFM*	8,400	27,000
COLLECTOR ONLY	8.00	5.46
TOTAL EQUIPMENT	8.54	5.95
TURNKEY SYSTEM	16.34	9.80

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR.

D. GENERALIZED COST DATA

A series of correlations were made to investigate the general relationship of the cost of equipment to the gas flow rate for the types of control systems discussed in this report. These correlations were made using the data presented in the previous section of this report. The points plotted on each graphical correlation are coded so that the process application which they represent can be identified. The same point symbol code was used in all of the graphs and it is fully explained in Table 133.

Scrubbers

Correlations were made for both the scrubber cost and for the total installed cost of the scrubber system as a function of the inlet gas flow rate in ACFM. Figure 74 shows the cost of the scrubber alone. The data falls fairly uniformly along a single line. This is to be expected because all of the scrubbers that have been considered in this section are of low to medium energy. The plotted points represent scrubbers of similar complexity.

Figure 75 shows the relation between the cost for installed scrubber systems and the inlet gas flow rate in ACFM. The majority of the data points fall along a straight line. As previously mentioned, all of the scrubber systems are of similar complexity. The only exception is the asphalt saturator application that uses a low energy scrubber with a 3 wt% solution of potassium permanganate as the scrubber liquor. Because of the lower operating energy which is required in this application, the system was less expensive. The direct operating cost of the wet scrubber in this application, however, increases because of the cost of the potassium permanganate that is required. Direct operating costs of wet scrubbers may be found in Figure 76. This graph starts curving up near its bottom end as the more fixed operating costs, such as operating and maintenance labor, become a more significant part of the total which, therefore, increases less rapidly with size.

Fabric Filters

Similar correlations were made for fabric filters. However, as Figure 77, 78, and 79 illustrate, due to the wide variability in the applications involved, no true correlation exists between the different applications on a gas flow rate basis. This is caused by the fact that the characteristics of the different particulates being collected require a different air-to-cloth ratio for each application. For inlet gas flow rates greater

TABLE 133

PLOTTING SYMBOL KEY

Process Area	Symbol
Kraft Pulp Mills	
— Conventional Recovery Boilers	⬡
— Controlled Odor Recovery Boilers	⬢
Ferroalloy Furnaces	
— Ferrosilicon Furnaces with Air Dilution Coolers	◇
— Silicon Metal Furnaces with Air Dilution Coolers	□
— Silicon Metal Furnaces with Evaporative Coolers	■
Grain Cleaning Houses	▽
Glass Manufacturing	▲
Crushed Stone and Aggregate Industry	
— Secondary and Tertiary Rock Crusher	○
— Crushed Stone and Aggregate Transfer	●
Asphalt Saturation	
— Asphalt Saturator	⬯
— Asphalt Blowing Still	⬮

than 100,000 ACFM, the air-to-cloth ratio approaches a constant value, and the relationship between size and cost becomes nearly linear. This can be expected; for as the size increases, the cost of labor and material for replacing the bags become the major part of the operating cost. And these bag replacement costs are directly proportional to the size of the unit. The capital costs of fabric filters are given as Figure 77, installed costs of filter systems appear in Figure 78, and direct operating costs of fabric filter systems are presented in Figure 79. All of the costs have been correlated with the inlet gas flow rate in ACFM. Actual costs of filters and systems for flow rates of 100,000 ACFM or less vary in this study between the dashed lines of these figures, and single, unique correlations of cost with gas flow rate to the filter system can not be established in this range.

Incinerators

There were only two applications in this study for which incinerator cost information was obtained. All of these units were thermal incinerators, and heat exchangers were specified for each unit. Inlet gas flow rates were between 10,000 and 60,000 ACFM.

The capital cost of the incinerator alone appears in Figure 80 as a function of the inlet gas flow rate. In Figure 81, the installed cost correlation has been plotted for these systems. In this range of inlet gas flow rates, the costs of installed systems increase significantly with increasing size. Differences in operating costs for medium and high efficiency incineration systems were not significant for the asphalt saturator application.

Electrostatic Precipitators

Capital costs of electrostatic precipitator units are presented graphically as Figure 83, and installed costs of precipitator systems are given in Figure 84. A high efficiency precipitator costs about 25 to 30 percent more than a medium efficiency unit, and a high efficiency precipitator system has a 15 to 20 percent greater installed cost than a medium efficiency system, for an identical inlet gas flow rate. The cost of the installed system varied from about 2 to 3.5 times that of the precipitator alone.

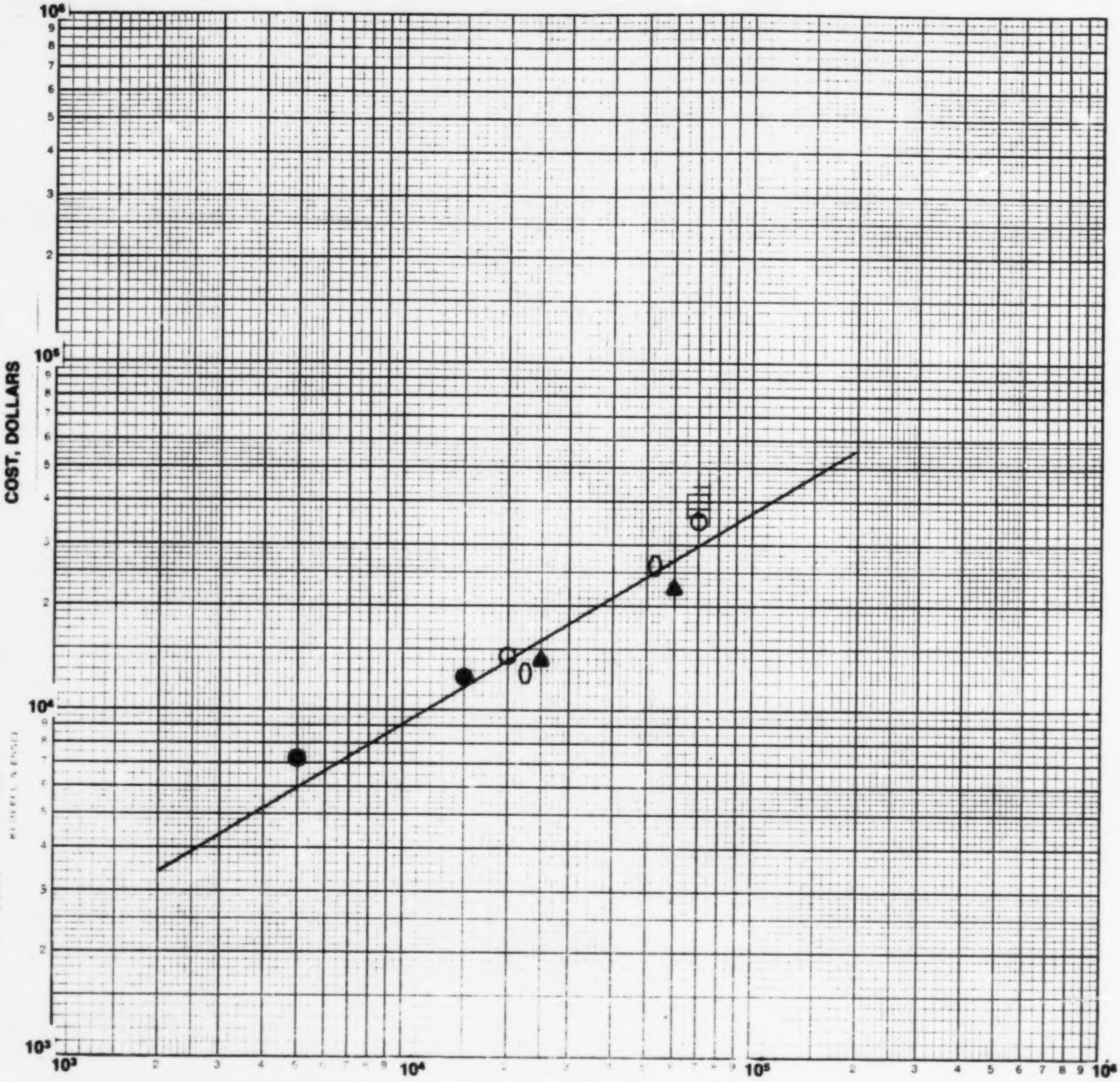
Figure 85 shows the direct operating costs of precipitators. The data indicate that the cost of operating a high efficiency unit is roughly 10% more than that of operating a medium efficiency unit, for the applications that have been studied. Nearly all of the increase is due to the increased use of electrical power.

Glass Fiber Mat Filters

Glass fiber mat filtration was used in only one application in this report. The only correlations necessary were made when the costs were presented in the previous section of this report.

FIGURE 74

CAPITAL COST OF WET SCRUBBERS ONLY



INLET GAS FLOW RATE, ACFM

FIGURE 75

TOTAL INSTALLED COST OF SCRUBBING SYSTEMS

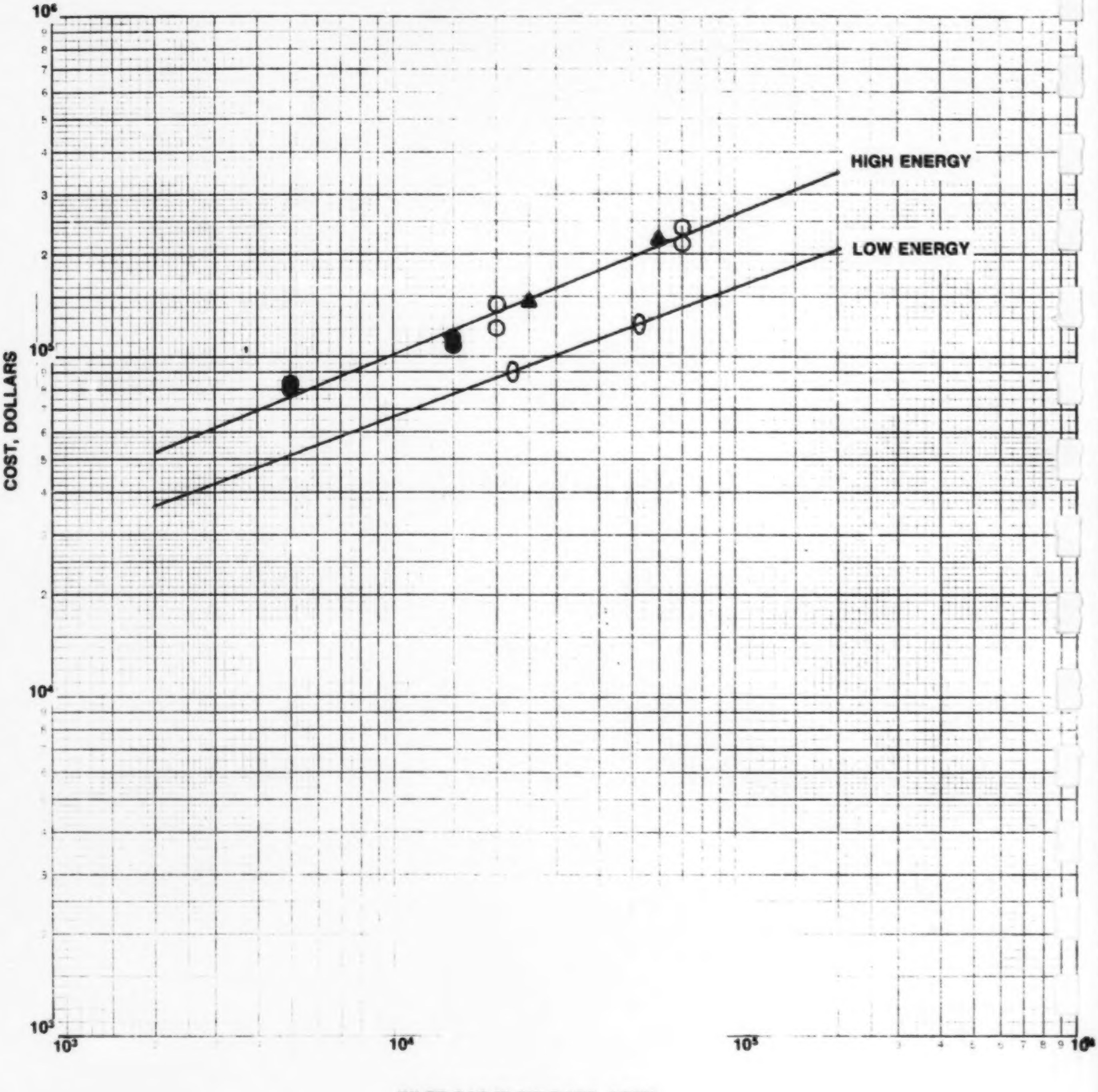


FIGURE 76

DIRECT OPERATING COST OF WET SCRUBBERS

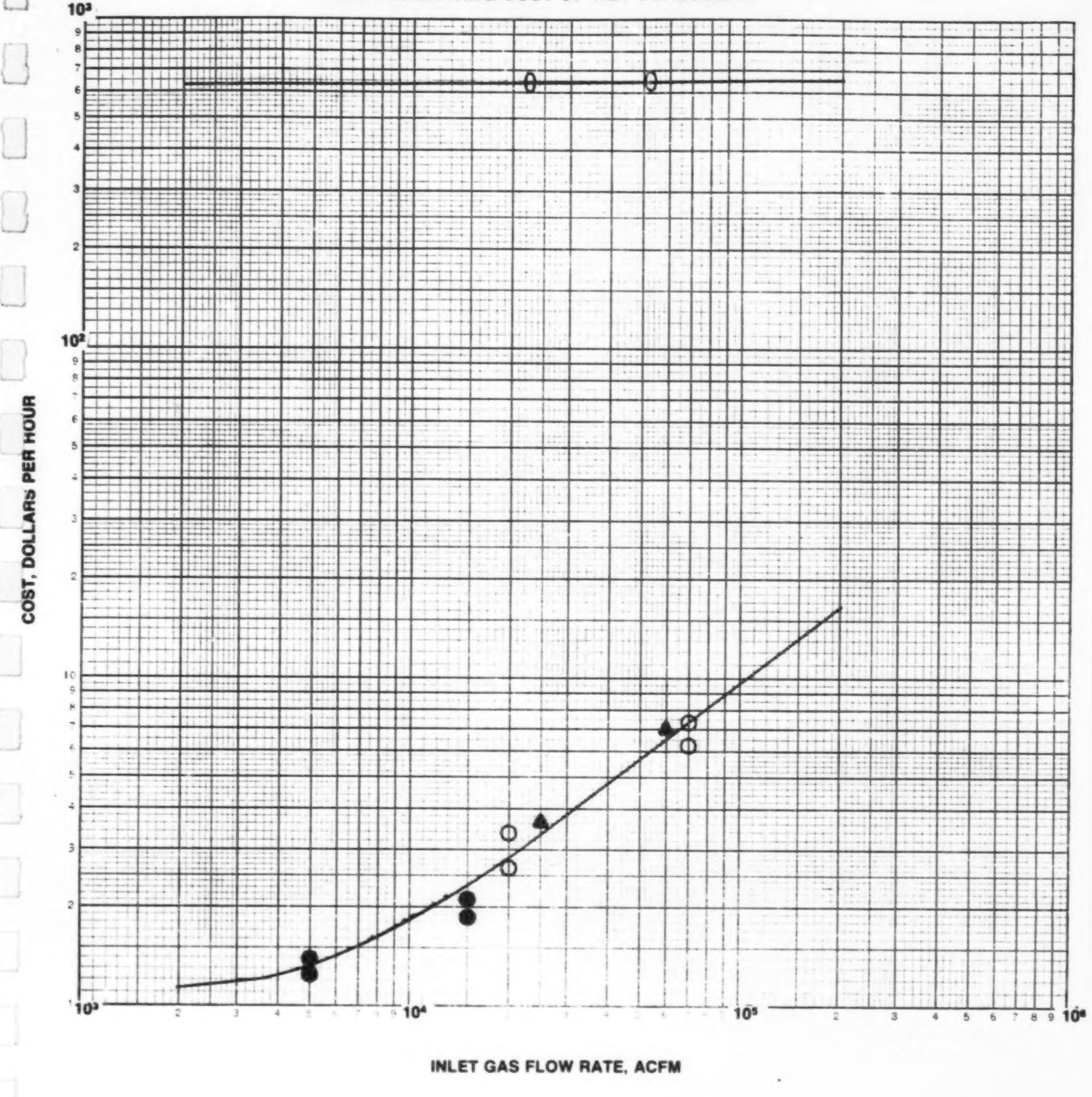


FIGURE 77

CAPITAL COSTS OF FABRIC FILTERS

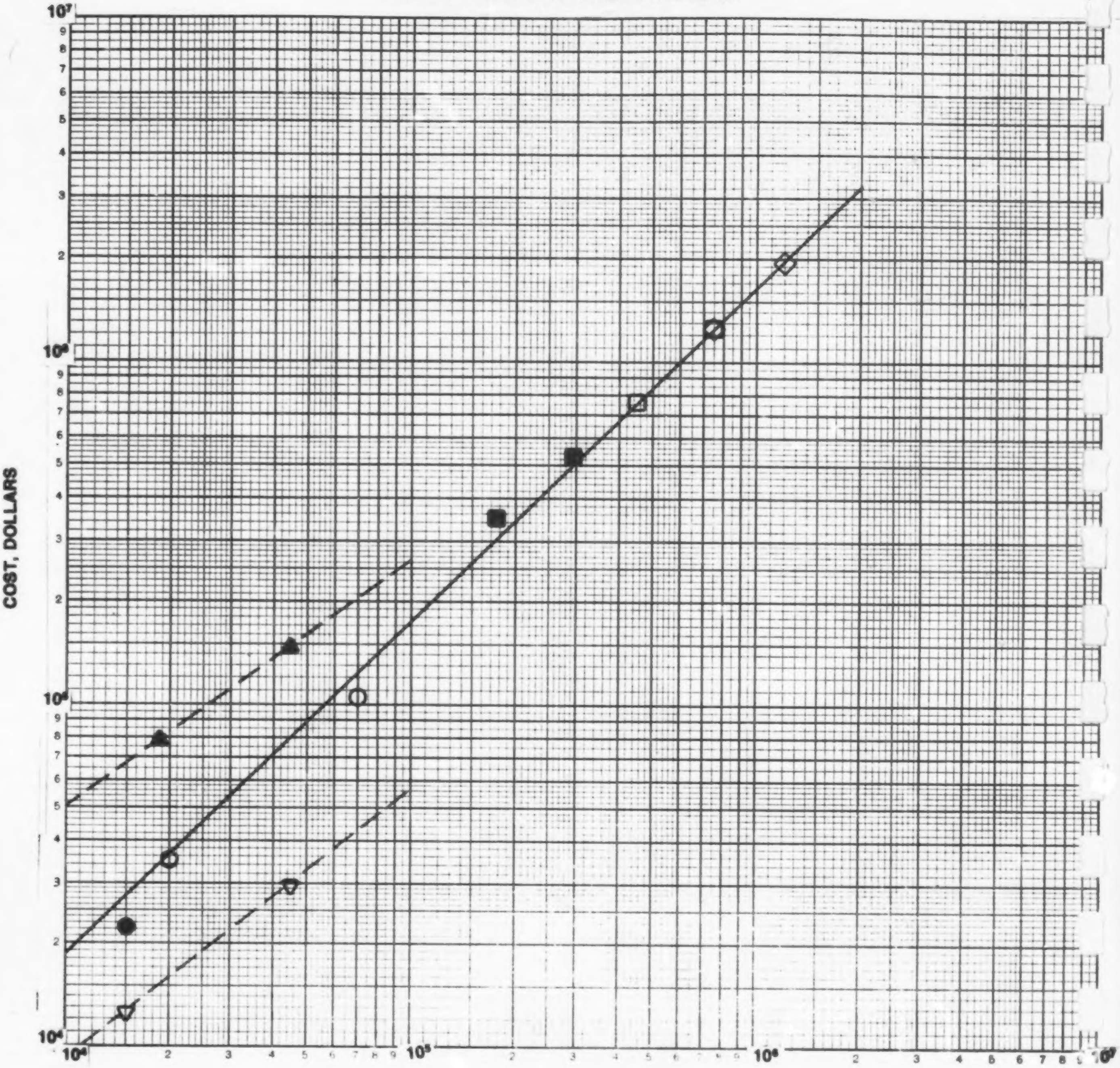


FIGURE 78

INSTALLED COSTS OF FABRIC FILTERS

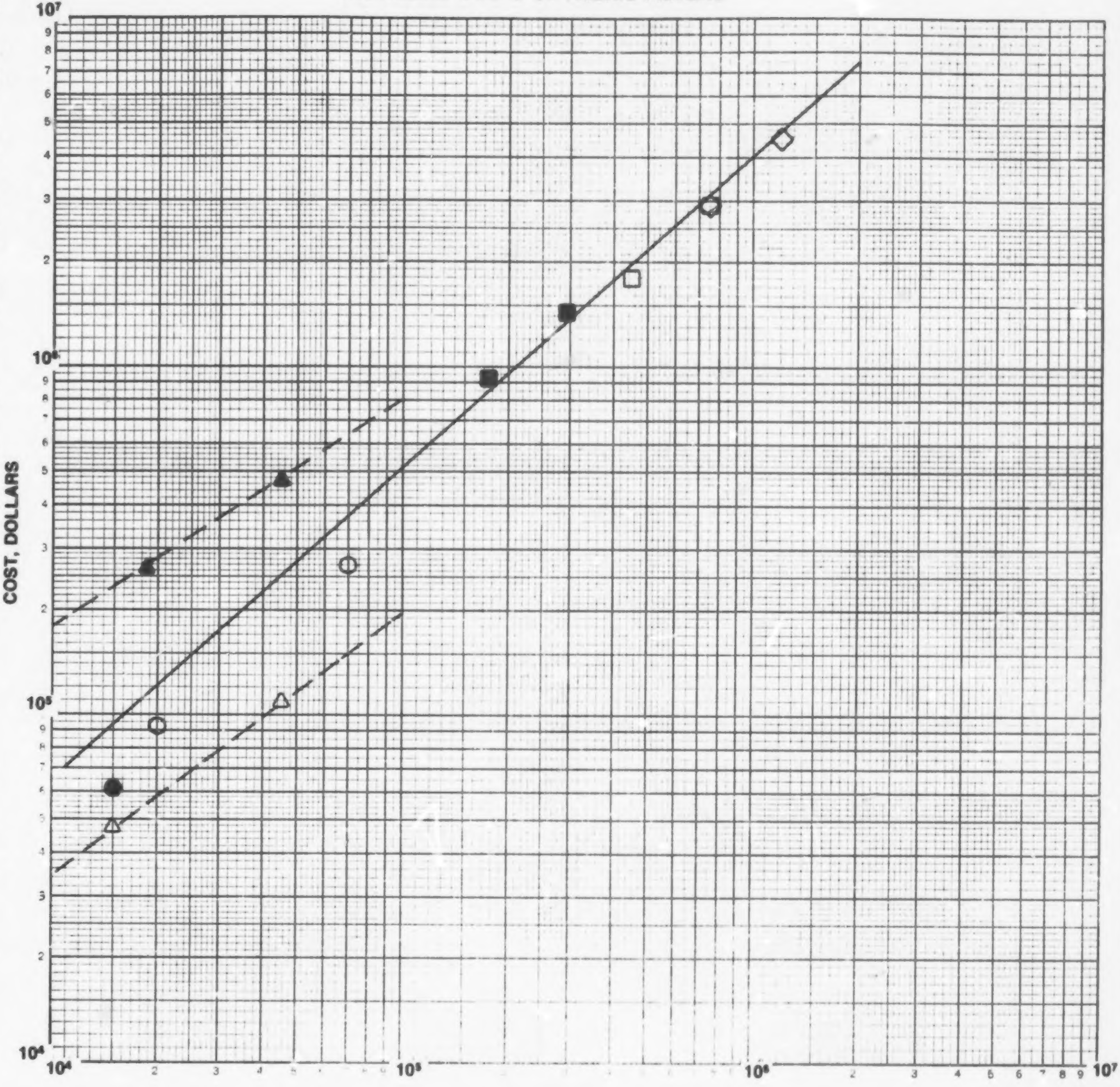


FIGURE 79

DIRECT OPERATING COSTS OF FABRIC FILTERS

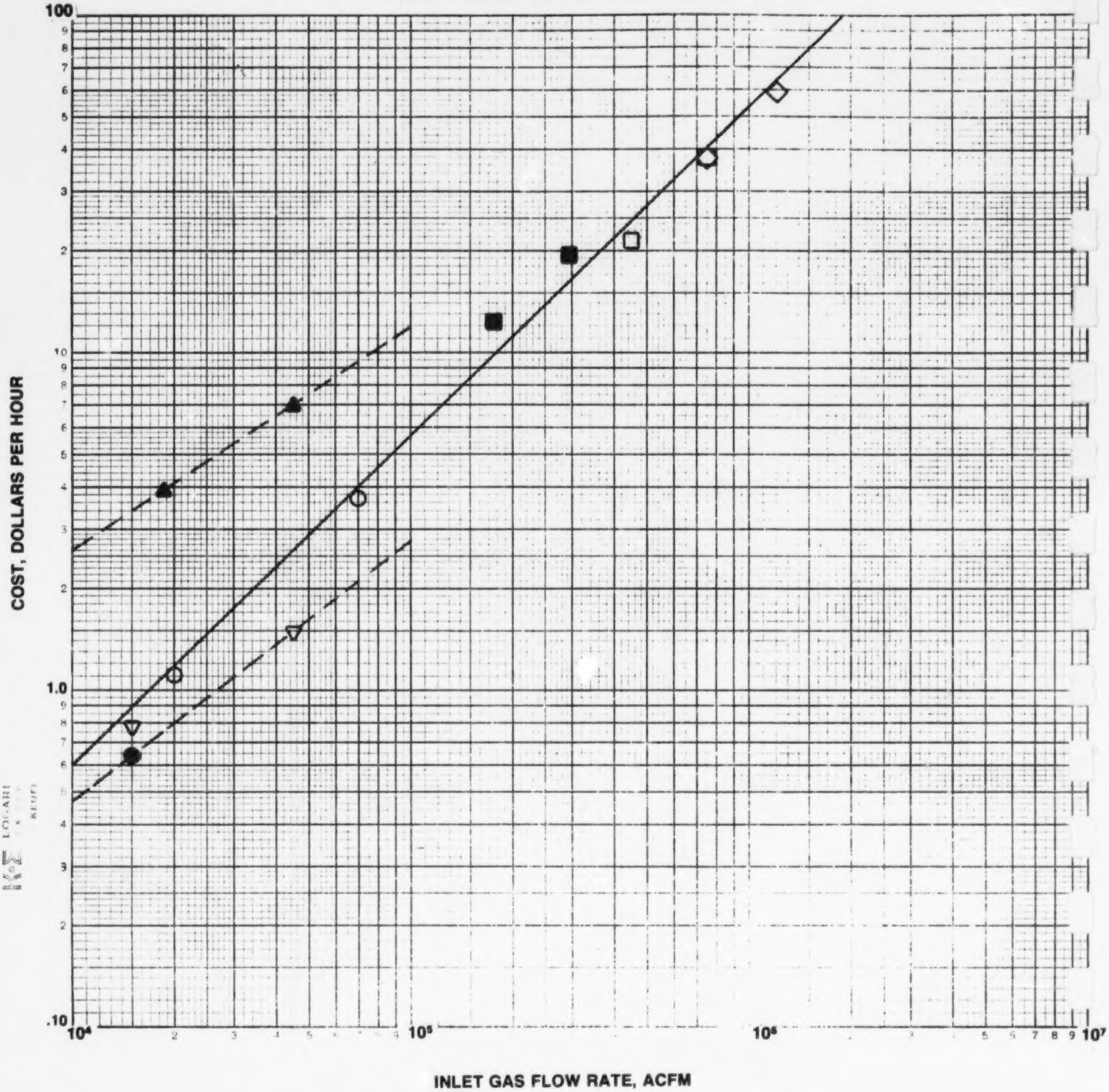
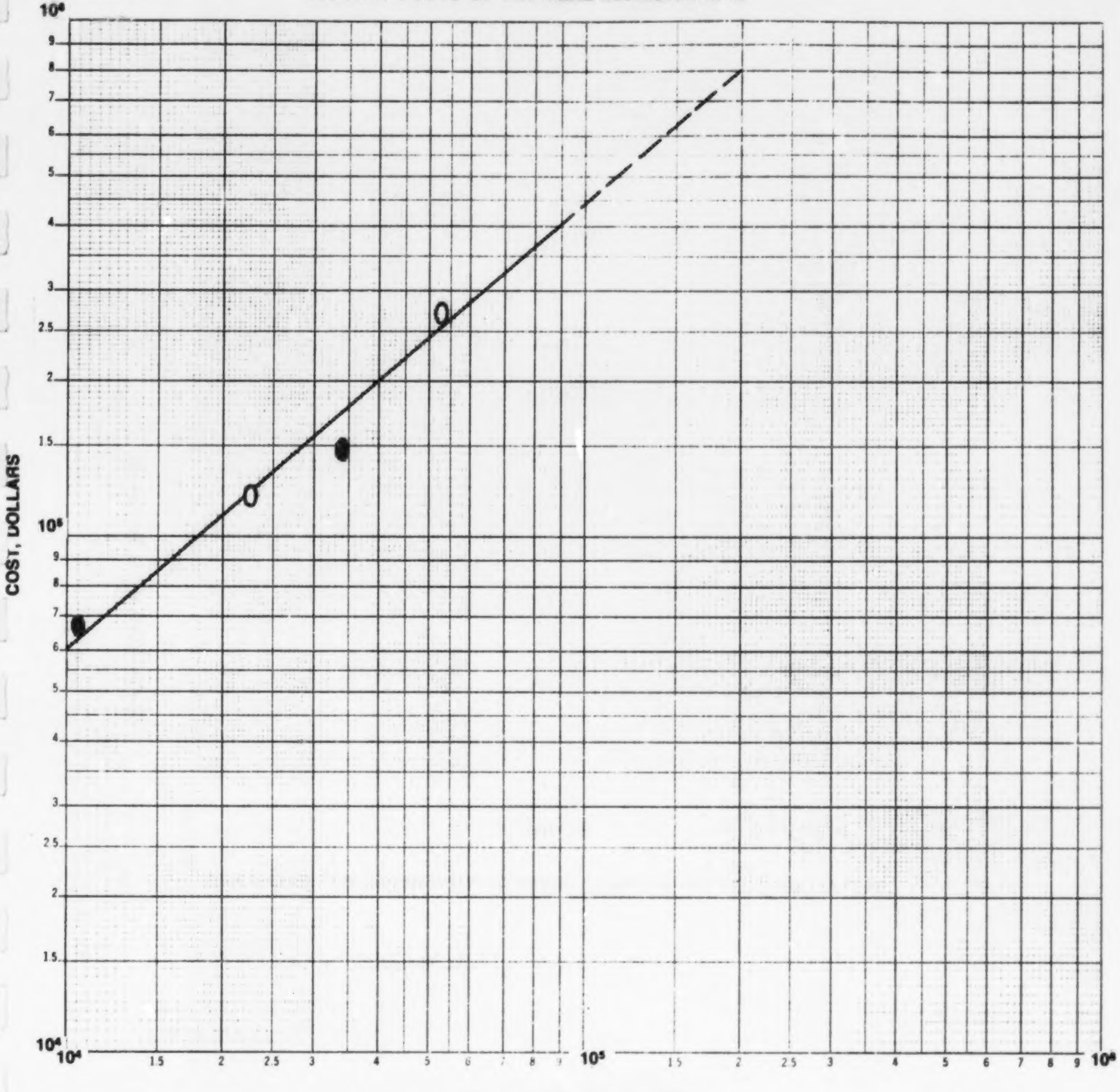


FIGURE 80

CAPITAL COSTS OF THERMAL INCINERATORS



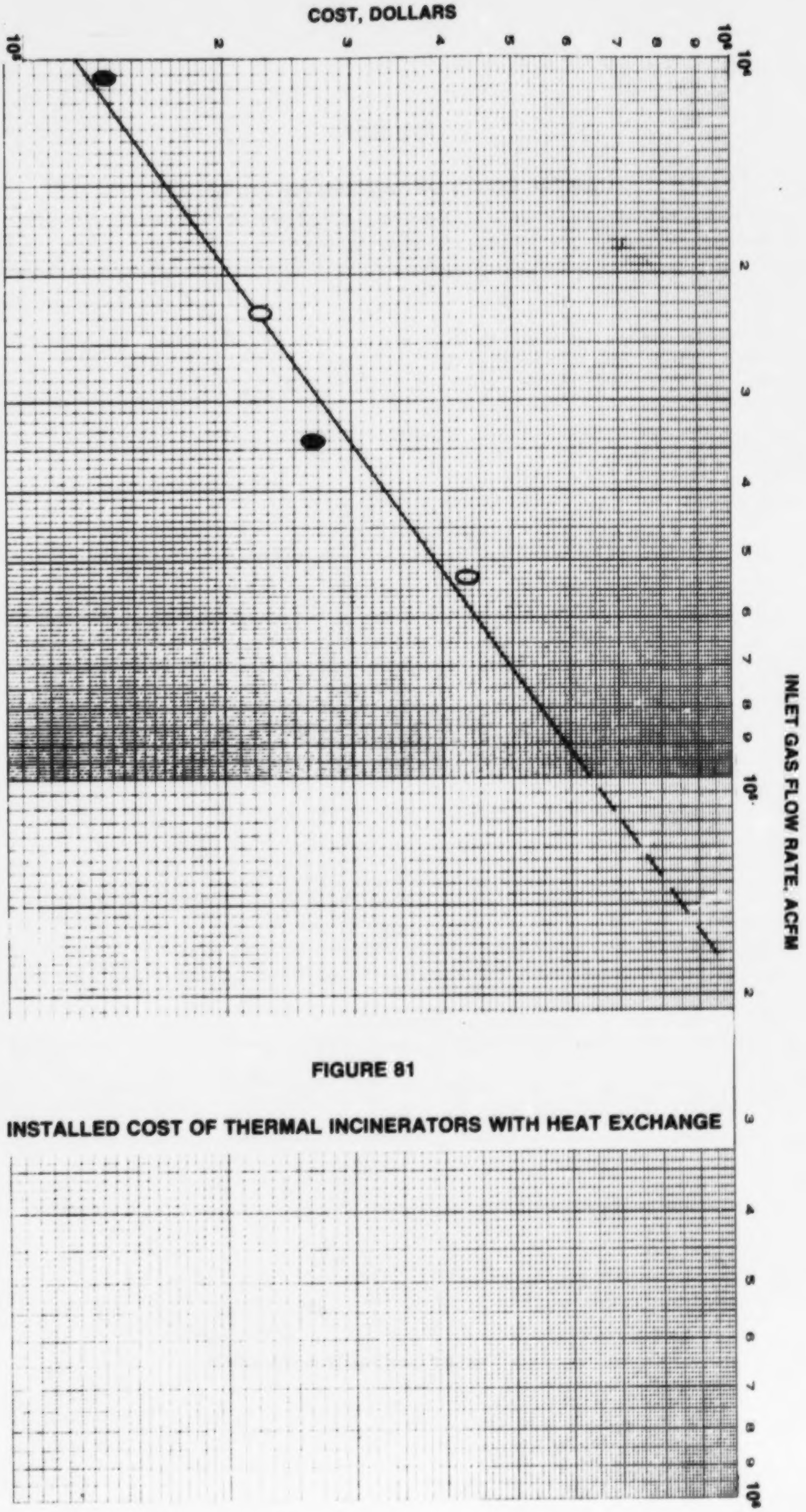


FIGURE 81

INSTALLED COST OF THERMAL INCINERATORS WITH HEAT EXCHANGE

FIGURE 82

DIRECT OPERATING COST
OF THERMAL INCINERATORS WITH HEAT EXCHANGE

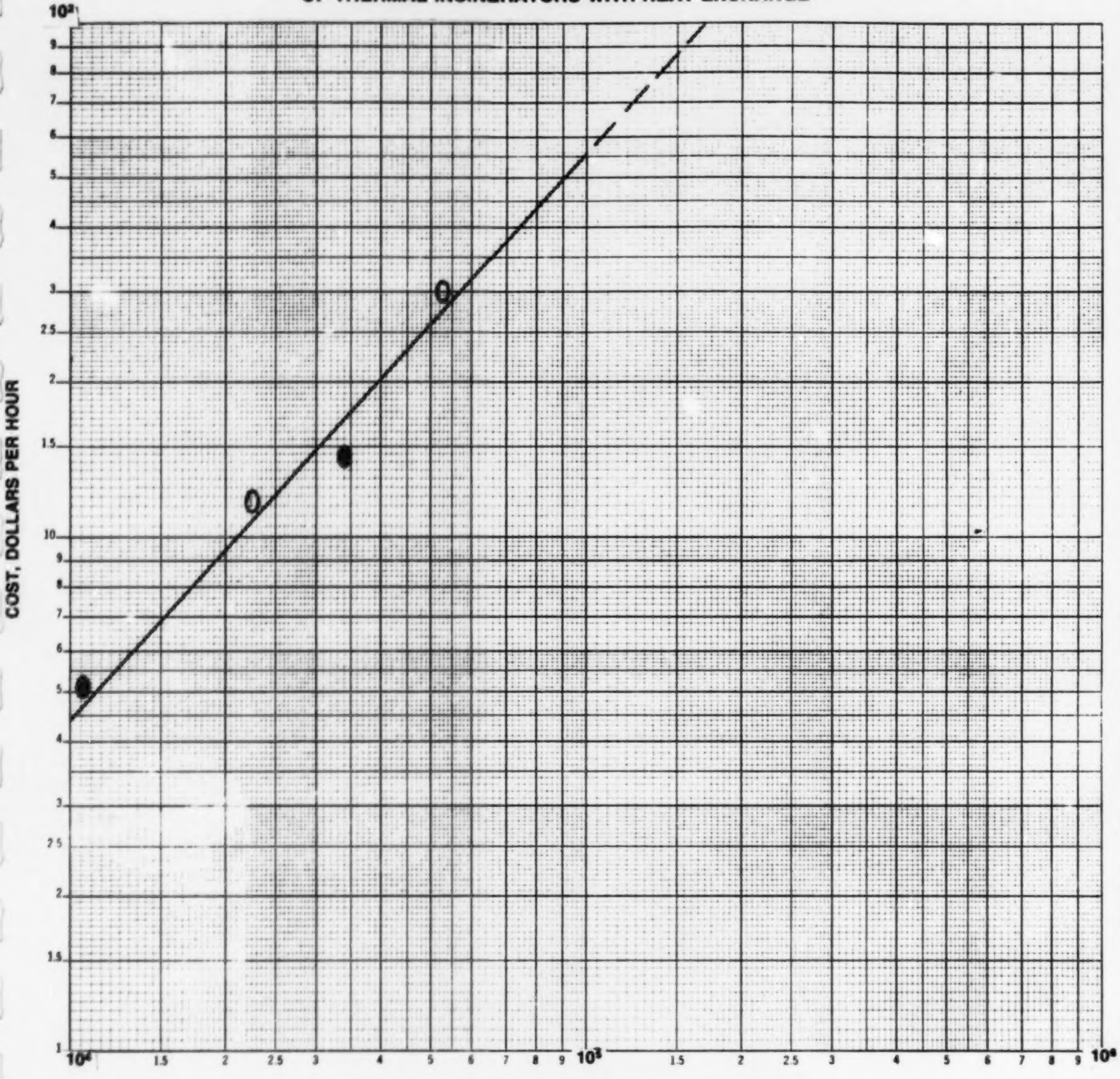


FIGURE 83

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS

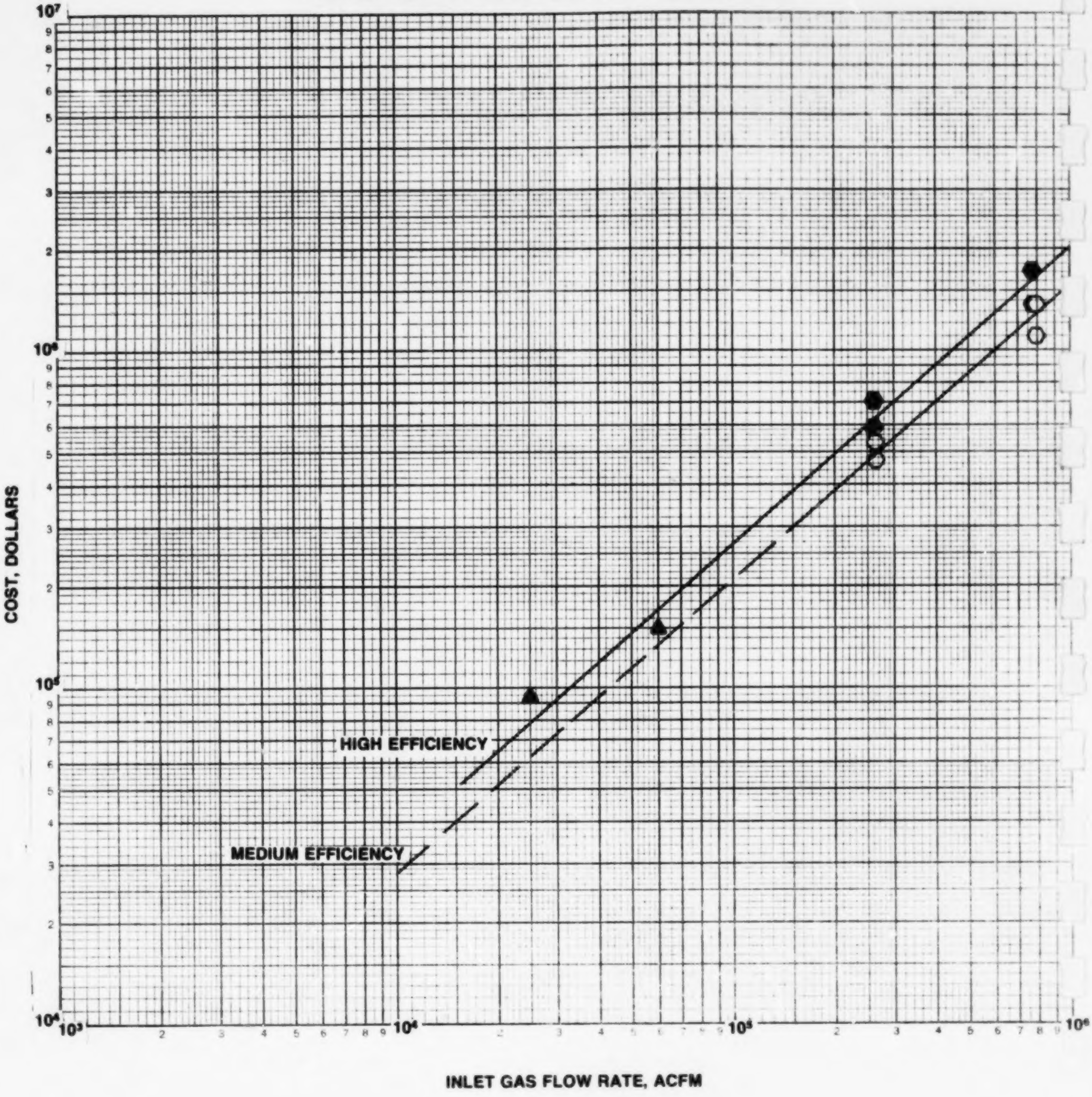


FIGURE 84

INSTALLED COST OF ELECTROSTATIC PRECIPITATORS

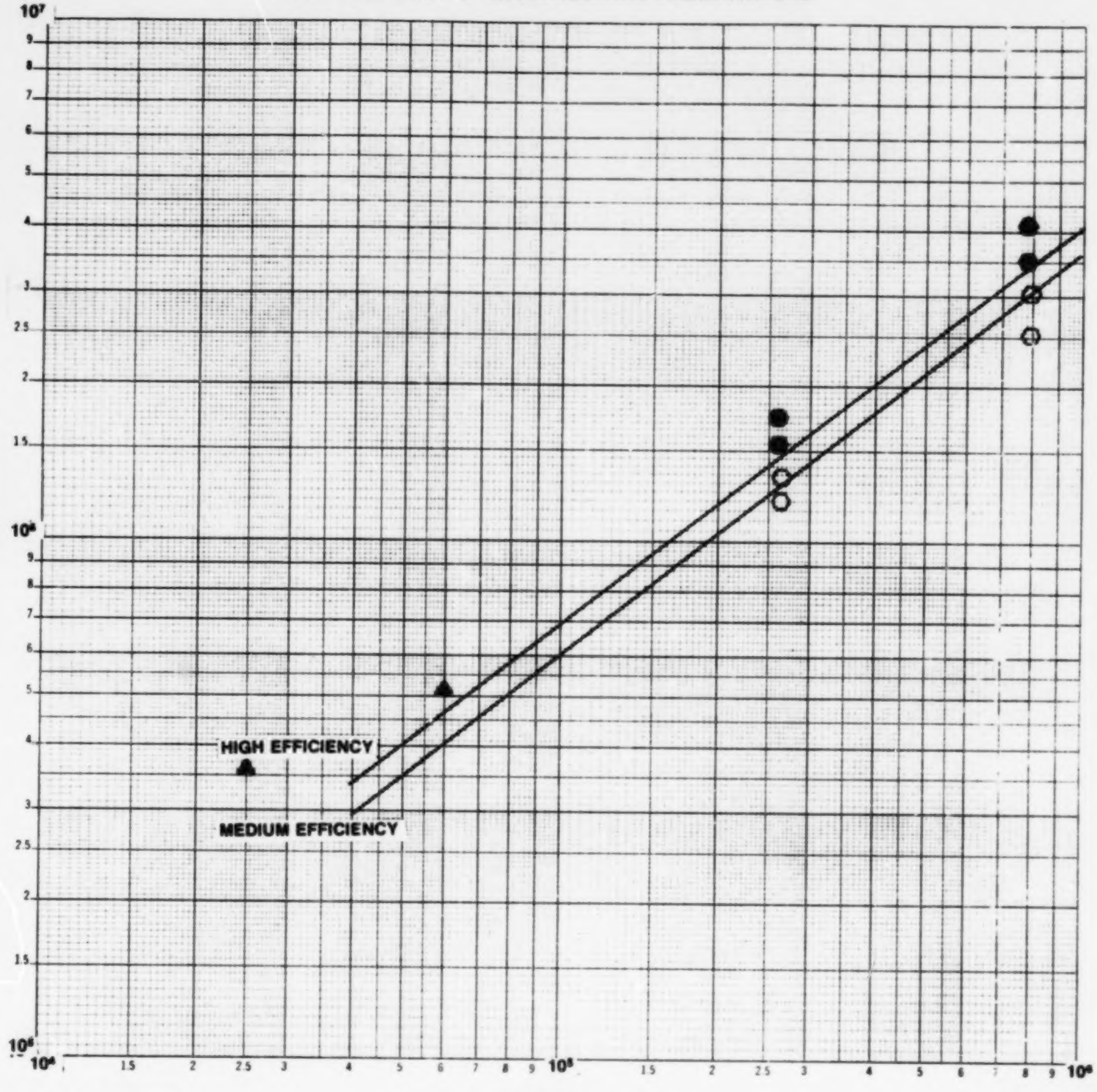
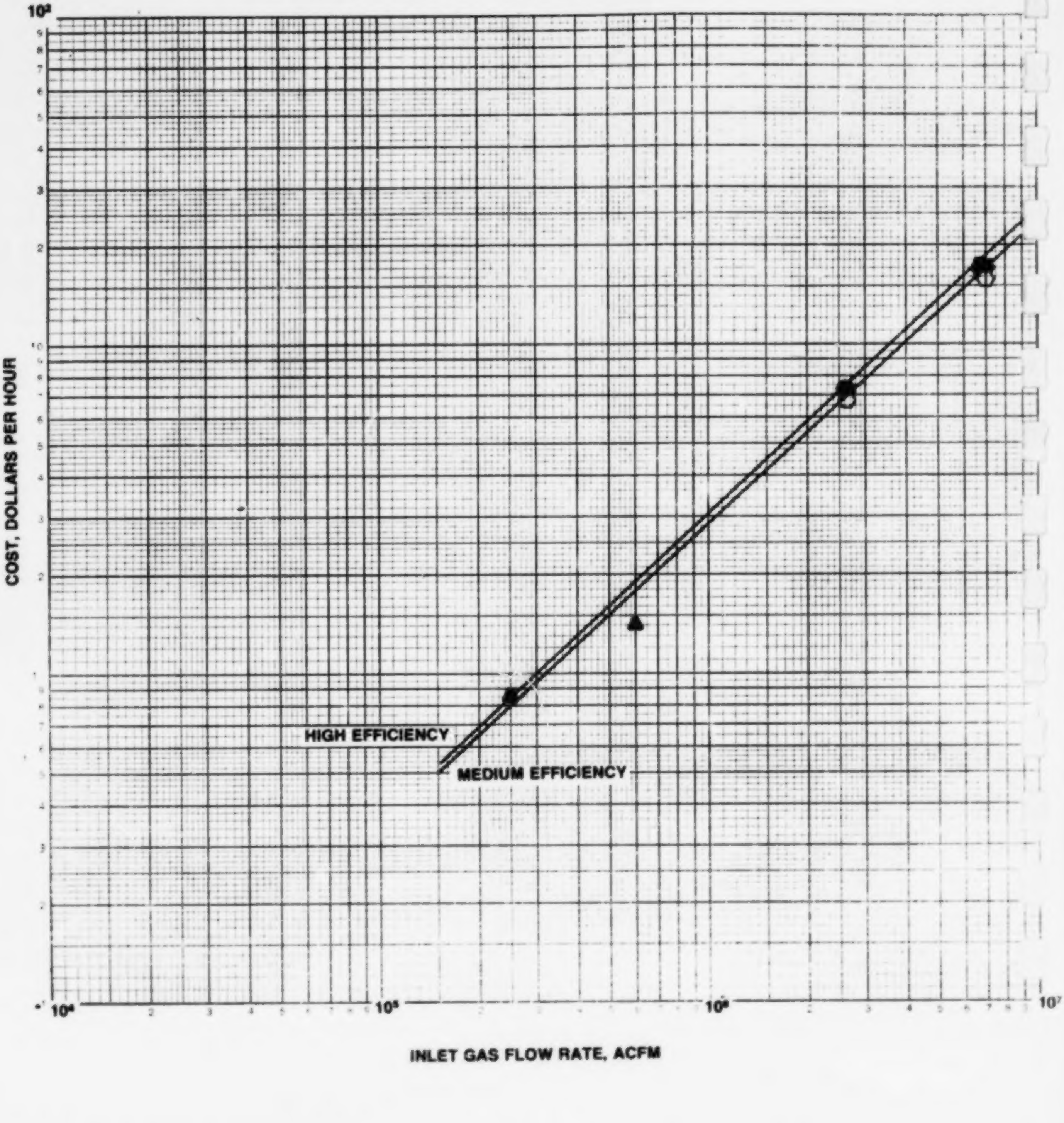


FIGURE 85

DIRECT OPERATING COST OF ELECTROSTATIC PRECIPITATORS



APPENDIX

A. SPECIFICATIONS FOR ABATEMENT EQUIPMENT

I. SCOPE

A. This specification covers vendor requirements for air pollution control equipment for the subject process. The intent of the specification is to describe the service as thoroughly as possible so as to secure vendor's proposal for equipment which is suitable in every respect for the service intended. Basic information is tabulated in Sections 2 and 3. The vendor should specify any of the performance characteristics which cannot be guaranteed without samples of process effluent.

B. The vendor shall submit a bid showing three separate prices as described below.

1. All labor, materials, equipment, and services to furnish one pollution abatement device together with the following:

   a. All ladders, platforms and other accessways to provide convenient access to all points requiring observation or maintenance.

   b. Foundation bolts as required.

   c. Six (6) sets of drawings, instructions, spare parts list, etc., pertinent to the above.

2. Auxiliaries including:

   a. Fan(s)

   b. Pump(s)

   c. Damper(s)

   d. Conditioning Equipment

   e. Conveying Equipment

3. A turnkey installation of the entire system including the following installation costs:

    a. Engineering

    b. Foundations and Support*

    c. Ductwork

    d. Stack

    e. Insulation

    f. Electrical

    g. Piping

    h. Painting

    i. Startup

    j. Performance Test

    k. Other

C. For the "pollution abatement device only" quotation, the vendor shall furnish the equipment FOB point of manufacture, and shall furnish as a part of this project competent supervision of the erection, which shall be by others.

D. Vendor shall furnish* the following drawings, etc., as a minimum:

1. With his proposal:

    a. Plan and elevation showing general arrangement.

    b. Typical details of collector internals proposed.

    c. Data relating to projected performance with respect to pressure drop, gas absorption efficiency, and particulate removal efficiency to operating parameters such as gas flow.

*This is a typical request. The member companies are NOT to furnish this material under the present project.

*Predicated on ideal soil conditions.

When the detailed analysis method is used to estimate operating and maintenance labor costs, a brief statement of the assumptions made will be helpful in combining the estimates of several member companies.

The least desirable method of estimating maintenance and operating labor costs involves the use of a *fraction of total capital cost*. Operating labor costs bear little relationship to capital cost of the equipment, and it may be true that increasing the capital cost will decrease the labor requirement (for example, where additional instrumentation is used to minimize operator attention). The use of a fraction of capital cost should therefore not be used as a basis for estimating operating labor in any case.

Maintenance costs are sometimes obtained by conducting industry-wide surveys and the results reported in terms of total dollars for labor and material or as a fraction of the installed cost of the equipment. For example, a survey of maintenance costs in the chemical process industries reported an annual expenditure of approximately 6% of total installed system cost for a wide variety of chemical equipment. It might be reasonable to allocate half of this cost to labor and half to spare parts and report a labor cost of 3% of the total installed cost. This is not recommended and should be used only when there is no other basis available. The use of this system and the source of the information on which the estimate is based should be clearly indicated.

IV. PROCESS PERFORMANCE GUARANTEE

A. The equipment will be guaranteed to reduce the particulate and/or gas contaminant loadings as indicated in the service description.

B. Performance test will be conducted in accordance with I.G.C.I. test methods where applicable.

C. Testing shall be conducted at a time mutually agreeable to the customer and the vendor.

D. The cost of the performance test is to be included in vendor's turnkey proposal.

E. In the event the equipment fails to comply with the guarantee at the specified design conditions, the vendor shall make every effort to correct any defect expeditiously at his own expense. Subsequent retesting to obtain a satisfactory result shall be at the vendor's expense.

V. GENERAL CONDITIONS

A. Materials and Workmanship

Only new materials of the best quality shall be used in the manufacture of items covered by this specification. Workmanship shall be of high quality and performed by competent workmen.

B. Equipment

Equipment not of vendor's manufacture, furnished as a part of this collector shall carry the manufacturer's guarantee.

C. Compliance with Applicable Work Standards and Codes

It shall be the responsibility of the vendor to design and manufacture the equipment specified in compliance with the specified codes.

2. Upon receipt of order:

    a. Proposed schedule of design and delivery.

3. Within 60 days of order:

    a. Complete drawings of equipment for approval by customer.

    b. 30 days prior to shipment:

        1) Certified drawings of equipment, six sets

        2) Installation instructions, six sets

    c. 30 days prior to startup:

        1) Starting and operating instructions, six sets

        2) Maintenance instructions and recommended spare parts lists, six sets

E. The design and construction of the collector and auxiliaries shall conform to the general conditions given in Section III and to good engineering practice.

B. INSTRUCTIONS FOR SUBMITTING COST DATA

Two forms (two copies each) are enclosed with each specification. They have been designed for the purpose of reporting the cost estimate prepared for each specification. The forms are titled:

A. Estimated Capital Cost Data

B. Annual Operating Cost Data

These forms will also be used to exhibit, in the final report for this study, averages of the three cost estimates for each process and equipment type. Because your costs will be averaged with those of other IGCI members, it is necessary to prepare them in accordance with instructions given in the following paragraphs.

A. Estimated Capital Cost Data

The upper part of this form should already be filled out for the particular application when you receive it. This information on operating conditions should be identical to that in the specification and is repeated only for the convenience of those reading the form.

You should fill in the estimated dollar amounts in the appropriate spaces on the bottom half of the form. It should not be necessary to add any information other than the dollar amounts. If you wish to provide a description of the equipment proposed, please do so on one or more separate sheets of paper, and attach it to the form. If any item is not involved in the equipment you are proposing, please indicate this by writing "none" in the space rather than leaving it blank or using a zero.

1. The "gas cleaning device" cost should be reported just as you would report a flange-to-flange equipment sale to the IGCI. That is, a complete device including necessary auxiliaries such as power supplies, mist eliminators, etc. Do NOT include such items as fans, solids handling equipment, etc., unless these are an integral part of your gas cleaning device.

2. "Auxiliaries" are those items of equipment which are frequently supplied with the gas cleaning device. There is a purely arbitrary distinction between those items included here and those included in the "Installation" costs.

Do NOT include any of the cost of erecting or installing auxiliaries in this category.

3. "Installation Cost" should include the field labor required to complete a turnkey installation as well as all of the material not in 1. or 2. In cases where the equipment supplier ordinarily erects the equipment but does not supply labor for foundations, etc., it is necessary to include an estimated cost for these items. General tradework, including rigging, erection, etc., should be included in the "Other" category.

The installation should be estimated for a new plant, or one in which there are no limitations imposed by the arrangement of existing equipment. Installation labor should be estimated on the basis that the erection will take place in an area where labor rates are near the U.S. average, and the distance from your plant is no more than 500 miles. Milwaukee, Wisconsin is an example of a city with near-average labor rates.

B. Annual Operating Cost Data

Some of the information will be supplied by Air Resources, such as unit costs for labor and utilities, and annualized capital charges. You should fill in the usage figures for the complete abatement system IN THE UNITS INDICATED BELOW.

Labor	hrs/year
Maintenance Materials	Dollars/year
Replacement Parts	Dollars/year
Electric Power	kw-hr/year
Fuel	MMBtu/year
Water (Process)	MM gal/year
Water (Cooling)	MM gal/year
Chemicals	Dollars/year (for each chemical used)

Air Resources will average the consumption figures reported, and convert them to dollar values for inclusion in the final report, using standard unit prices.

Be sure that the operating factor, indicated on the form in hours per year, is used for estimating the utility and labor requirements.

Guidelines for Operating Cost Estimates

The estimates of labor cost involved for operating and maintaining air pollution control systems are less likely to be based on first-hand knowledge than are the estimates of capital cost for the gas cleaning equipment and system installation. In order to make comparable and consistent estimates of these costs, some general rules should be used by all of the participants in the program. This section describes the rules which should be followed in making the estimates, and for describing the estimating basis in the reports prepared for the EPA.

Three alternative bases may be used for estimating the labor cost for operation and maintenance of air pollution systems:

1. Direct first-hand knowledge of similar systems.
2. Detailed analysis of incremental labor requirements.
3. Percentage of first cost.

These alternatives are listed in order of preference; that is, direct first-hand knowledge of labor costs is the most desirable, and a percentage of the first cost of the system, the least desirable basis for estimating. The member companies are requested to indicate which of these bases was used in the preparation of each labor cost estimate.

Direct first-hand knowledge comprises detailed records of the man-hours employed by the owner of an air pollution control system for operation and/or maintenance of the equipment.

This information should be sufficiently detailed to determine that the time was actually spent in connection with the operating or maintenance function for the abatement system, and not simply an arbitrary allocation of operators' or mechanics' time between a process system and the associated abatement equipment. Such data should be used only if it is available for a system similar to that being quoted under this contract. A system should be considered similar only if it is used within the subject industry and on substantially the same process as that being quoted. If the process size is significantly different from that which is the subject of the quotation, the labor costs may be scaled up or down on the basis of realistic appraisals of the difference in requirements between large and small systems. It is not realistic to scale labor costs in proportion to the size of the system.

Although first-hand information is the most desirable basis for estimating maintenance and operating costs, it is unlikely that acceptable first-hand information will be available often to the member companies. When it is used, the member company should indicate the source of the data; i.e., system owned and operated by member, feedback from customer, industry or user survey program, etc.

A *detailed analysis* of probable costs is likely to be the best method available to the member companies for estimating operating and maintenance labor. A satisfactory detailed analysis need not be complex nor time-consuming. However, the estimate should be made in sufficient detail that man-hour allocations are made to specific functions, as opposed to blanket assumptions of total operating or total maintenance labor. For example, the labor required to rebalance the fan wheel and replace defective belts on an annual basis is a reasonable item with regard to level of detail.

When using this method, it is important to define clearly the assumptions made with regard to the circumstances of system operation. Some of these assumptions are indicated in a general way below:

1. Operating labor.
    a. Will the abatement system be operated by the same crew charged with operation of the production equipment? If yes, operator time should be allocated to the new abatement system.
    b. Are regular logs of operation likely to be helpful in obtaining best operation of the abatement equipment?
    c. Is additional supervisory time required? If yes, some supervisor time should be allocated to the abatement system.
    d. Will any special operator skill be required which would limit the ability of production equipment operators to serve as abatement system operators?
2. Maintenance labor.
    a. Will maintenance functions be performed routinely throughout the year, or at annual or semi-annual equipment maintenance shutdown periods?
    b. Have routine maintenance and inspection procedures been recommended?
    c. Will there be any special requirements for labor to purchase or inventory spare parts?
3. Can there be any labor credit for improvements in production equipment operation due to the installation of the abatement system?

C. CITY COST INDICES

Average 1969 Construction Cost & Labor Indices						Historical Average	
City	Index		City	Index		Year	Index
	Labor	Total		Labor	Total	1969	100
Albany, N.Y.	98	100	Milwaukee, Wi.	103	108	1968	91
Albuquerque, N.M.	86	95	Minneapolis, Mn.	99	98	1967	86
Amarillo, Tx.	87	84	Mobile, Al.	94	90	1966	83
Anchorage, Ak.	131	148	Montreal, Cn.	77	89	1965	79
Atlanta, Ga.	88	94	Nashville, Tn.	79	82	1964	78
Baltimore, Md.	90	93	Newark, N.J.	122	109	1963	76
Baton Rouge, La.	83	88	New Haven, Ct.	102	100	1962	74
Birmingham, Al.	79	86	New Orleans, La.	89	95	1961	72
Boston, Ma.	106	103	New York, N.Y.	132	118	1960	71
Bridgeport, Ct.	104	102	Norfolk, Va.	73	77	1959	69
Buffalo, N.Y.	104	107	OklahomaCity,Ok.	82	88	1958	67
Burlington, Vt.	86	90	Omaha, Nb.	90	93	1957	65
Charlotte, N.C.	70	75	Philadelphia, Pa.	106	101	1956	63
Chattanooga, Tn.	81	84	Phoenix, Az.	101	97	1955	59
Chicago, Ill.	107	103	Pittsburgh, Pa.	110	106	1954	58
Cincinnati, Oh.	108	104	Portland, Me.	82	87	1953	57
Cleveland, Oh.	121	112	Portland, Or.	102	103	1952	55
Columbus, Oh.	106	99	Providence, R.I.	98	97	1951	53
Dallas, Tx.	86	89	Richmond, Va.	76	79	1950	49
Dayton, Oh.	100	103	Rochester, N.Y.	110	107	1949	48
Denver, Co.	94	91	Rockford, Ill.	109	109	1948	48
Des Moines, Ia.	93	96	Sacramento, Ca.	117	110	1947	43
Detroit, Mi.	117	111	St. Louis, Mo.	110	103	1946	35
Edmonton, Cn.	80	83	Salt Lake City, Ut.	93	95	1945	30
El Paso, Tx.	77	83	San Antonio, Tx.	82	82	1944	29
Erie, Pa.	98	99	San Diego, Ca.	111	107	1943	29
Evansville, In.	93	97	San Francisco, Ca.	124	109	1942	28
Grand Rapids, Mi.	103	99	Savannah, Ga.	72	77	1941	25
Harrisburg, Pa.	90	92	Scranton, Pa.	94	96	1940	24
Hartford, Ct.	104	100	Seattle, Wa.	104	99	1939	23
Honolulu, Hi.	99	109	Shreveport, La.	82	89	1938	23
Houston, Tx.	92	89	South Bend, In.	99	97	1937	23
Indianapolis, In.	97	98	Spokane, Wa.	101	100	1936	20
Jackson, Ms.	73	75	Springfield, Ma.	99	97	1935	20
Jacksonville, Fl.	78	79	Syracuse, N.Y.	105	103	1934	20
Kansas City, Mo.	94	93	Tampa, Fl.	81	84	1933	18
Knoxville, Tn.	82	82	Toledo, Oh.	105	105	1932	17
Las Vegas, Nv.	115	107	Toronto, Cn.	84	93	1931	20
Little Rock, Ar.	78	81	Trenton, N.J.	114	103	1930	22
Los Angeles, Ca.	113	102	Tulsa, Ok.	85	89	1929	23
Louisville, Ky.	92	93	Vancouver, Cn.	81	91	1928	23
Madison, Wi.	95	98	Washington, D.C.	98	94	1927	23
Manchester,N.H.	89	92	Wichita, Ks.	85	90	1926	23
Memphis, Tn.	83	82	Winnipeg, Cn.	62	82	1925	23
Miami, Fl.	98	94	Youngstown, Oh.	107	106	1924	23

D. AVERAGE HOURLY LABOR RATES BY TRADE

Trade	1970	1969	1968	1967	1966
Common Building Labor	$5.00	$4.55	$4.10	$3.85	$3.65
Skilled Average	6.85	6.05	5.50	5.15	4.90
Helpers Average	5.15	4.65	4.20	4.00	3.85
Foremen (usually 35¢ over trade)	7.20	6.40	5.85	5.50	5.25
Bricklayers	7.15	6.40	5.85	5.55	5.35
Bricklayers Helpers	5.20	4.70	4.30	4.05	3.95
Carpenters	6.95	6.15	5.40	5.10	4.90
Cement Finishers	6.75	5.90	5.30	5.05	4.85
Electricians	7.50	6.45	5.95	5.60	5.45
Glaziers	6.25	5.50	5.10	4.75	4.60
Hoist Engineers	7.05	5.90	5.40	5.10	4.85
Lathers	6.60	5.95	5.45	5.20	5.05
Marble & Terrazzo Workers	6.45	5.60	5.25	5.05	4.90
Painters, Ordinary	6.20	5.45	5.05	4.75	4.50
Painters, Structural Steel	6.50	5.80	5.30	4.95	4.80
Paperhangers	6.30	5.60	5.15	4.75	4.55
Plasterers	6.60	5.95	5.50	5.15	5.00
Plasterers Helpers	5.30	4.85	4.45	4.15	4.00
Plumbers	7.75	6.90	6.15	5.75	5.55
Power Shovel or Crane Operator	7.20	6.20	5.65	5.35	5.05
Rodmen (Reinforcing)	7.30	6.35	5.80	5.45	5.15
Roofers, Composition	6.30	5.55	5.05	4.75	4.65
Roofers, Tile & Slate	6.35	5.60	5.10	4.85	4.80
Roofers Helpers (Composition)	4.75	4.45	4.00	3.75	3.55
Steamfitters	7.70	6.90	6.10	5.70	5.50
Sprinkler Installers	7.70	6.90	6.10	5.70	5.50
Structural Steel Workers	7.45	6.45	5.90	5.55	5.25
Tile Layers (Floor)	6.50	5.60	5.20	4.90	4.80
Tile Layers Helpers	5.25	4.80	4.35	4.15	4.05
Truck Drivers	5.15	4.60	4.30	3.95	3.65
Welders, Structural Steel	7.15	6.35	5.80	5.45	5.10

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E. LIST OF STANDARD ABBREVIATIONS

feet or foot	ft
inch or inches	in.
ton or tons	ton
pound or pounds	lb
hours or hours	hr
minute or minutes	min
parts per million	ppm
grain or grains	gr
weight percent	wt.%
actual cubic feet per minute	ACFM
standard cubic feet per minute	SCFM
dry standard cubic feet per minute	DSCFM
standard cubic feet	SCF
actual cubic feet	ACF
British thermal units	Btu
odor units	o.u.
volume	vol
mole	mol
gallon	gal
per cent	%
dollars	$
degrees Fahrenheit	°F
pounds per square inch gauge	psig
change of pressure (delta pressure)	ΔP
water column (pressure)	w.c.
change of temperature (delta temperature)	ΔT
temperature	Temp
feet per minute	FPM
dry standard cubic feet	DSCF
cubic feet	ft^3
revolutions per minute	rpm
gallons per minute	gpm
millions (10^6)	MM
atmospheres gage (pressure)	atmg
milligrams	mg
micrograms	yg
international unit	IU
hundred weight (100 pounds)	cwt
hydrocarbon	Hcbn
United States pharmacopoeia	USP

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